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ELEMENTARY SCHOOL SCIENCE--A GUIDE TO CURRENT RESEARCH.

BY- DUNFEE, MAXINE

ASSOCIATION FOR SUPERVISION AND CURRICULUM DEV.

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ELEMENTARY SCHOOL SCIENCE RESEARCH STUDIES ARE CATEGORIZED AND DESCRIBED IN THIS BOOKLET DESIGNED FOR CLASSROOM TEACHERS AND CURRICULUM WORKERS. ALTHOUGH MAJOR EMPHASIS OF THE REVIEW IS ON STUDIES PUBLISHED DURING THE 1960'S, OLDER STUDIES OF MAJOR SIGNIFICANCE ARE INCLUDED. A MAJORITY OF THE REVIEWS IS BASED ON REPORTS THAT APPEARED AS JOURNAL ARTICLES OR SUMMARIES FROM DISSERTATION ABSTRACTS. MAJOR CATEGORIES OF STUDIES INCLUDE THOSE THAT DEAL WITH (1) EDUCATIONAL OBJECTIVES, (2) STUDENTS' SCIENCE INTERESTS, (3) CONCEPT DEVELOPMENT, (4) INDIVIDUAL DIFFERENCES, (5) LEARNING EXPERIENCES, (6) INQUIRY AND DISCOVERY LEARNING, (7) EVALUATION, (8) TEXTBOOKS, (9) PROGRAMED LEARNING, (10) RADIO AND TELEVISION, (11) FILMS, (12) SCIENCE EQUIPMENT, AND (13) PRESERVICE AND INSERVICE TEACHER EDUCATION. INDIVIDUAL REVIEWS ARE BRIEF AND GENERALLY INCLUDE AN EXPLANATION OF WHAT WAS DONE AND A SUMMARY OF MAJOR FINDINGS. ALTHOUGH GENERAL COMMENTS ARE INCLUDED, NO ATTEMPT IS MADE TO ANALYZE DESIGNS OR EVALUATE TECHNIQUES OR RESULTS. A LIST OF COMPLETE CITATIONS FOR ALL STUDIES REVIEWED IS INCLUDED. THIS DOCUMENT IS ALSO AVAILABLE FOR $2.25 FROM THE ASSOCIATION FOR SUPERVISION AND CURRICULUM DEVELOPMENT, 1201 SIXTEENTH STREET, N.W., WASHINGTON, D.C. 20036. (AG)

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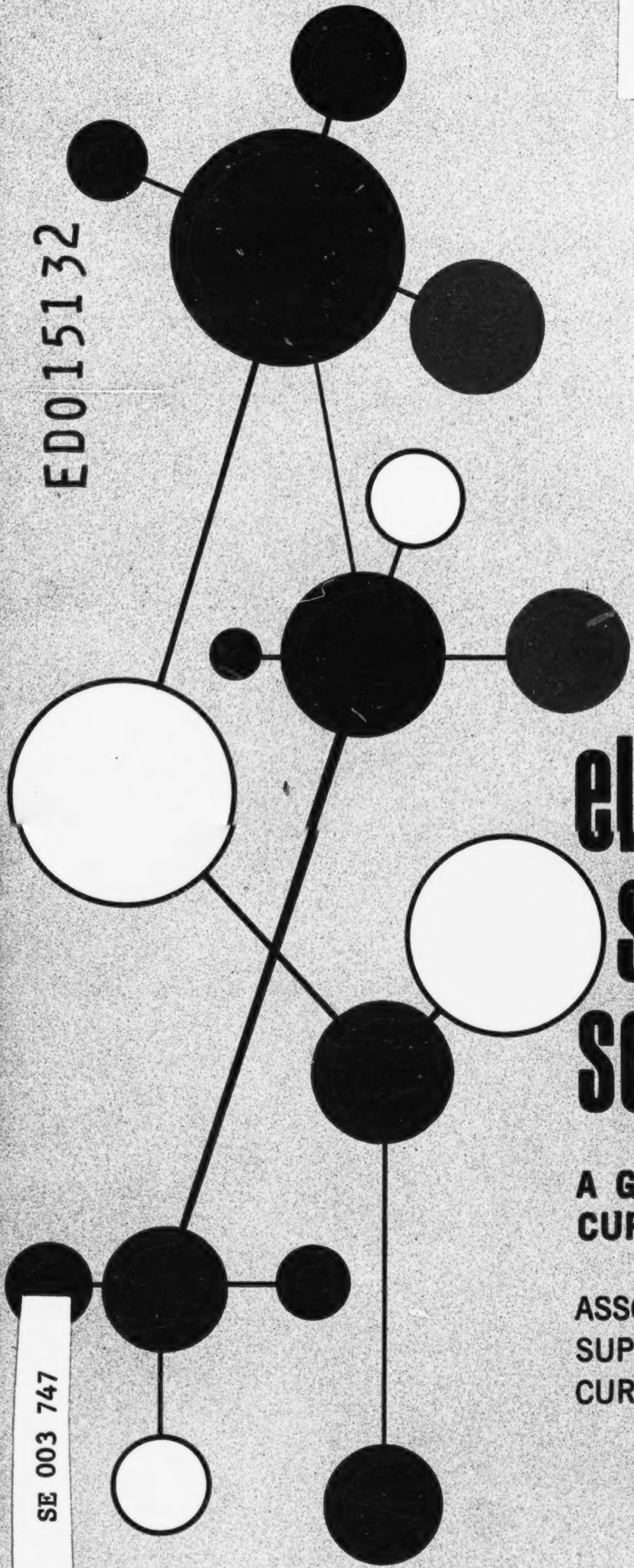

Maxine Dunfee

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Foreword

As SCHOLARS review the developments in science and mathematics education during the past decade, their opinions differ concerning the influence of Sputnik I, but few are unimpressed with the progress made at all educational levels in these fields since 1957. Replacing the earlier ASCD publication, *Elementary School Science: Research, Theory and Practice* by Maxine Dunfee and Julian Greenlee, Dr. Dunfee's new booklet offers a comprehensive survey of more recent research developments and current thinking in elementary science.

Elementary School Science: A Guide to Current Research is characterized by an objectivity seldom encountered even in the field of science. Innovations and research in the many facets of science education (objectives, curriculum development, methods, materials, evaluation, teacher education) are summarized and reported. Weighing and appraising are left to the reader, with whom, in the final analysis, these functions always belong. An extensive bibliography provides the reader with original sources and related readings.

ASCD is pleased to present this fine addition to the series of booklets on current curriculum research.

May 1967

J. HARLAN SHORES
President, 1967-68
Association for Supervision
and Curriculum Development

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Introduction

IN RECENT years science education has become an established part of the elementary school curriculum. It is no longer necessary to convince educators and the public in general that those who live in a scientific world should know something about it. Rather, the current concern is the improvement of science education for children, a concern which has as its focus identification of defensible objectives, reconstruction of the curriculum, utilization of pupil interests, studies of concept development and learning, encouragement of inquiry and discovery, evaluation of achievement, development of effective teaching resources, and more adequate preservice and in-service education.

This booklet was planned for teachers and curriculum workers who need a guide to current research but may not have time or opportunity to locate and assemble studies pertinent to their needs. While some general comments about various research efforts appear here and there in the text, there has been no consistent attempt to analyze in detail the designs of the studies or to evaluate their techniques or results. In fact, it would have been impossible to do so adequately.

On the other hand, the summaries of studies related in purpose appear together and include sufficient detail to help the reader know whether or not further exploration of original reports may be profitable.

As this booklet comes from the press, new research is appearing almost daily—new efforts to solve the persistent problems of effective curriculum construction in elementary science and its implementation. All those who had a part in the preparation of this booklet hope that it will contribute in some small way to efforts to further extend and improve elementary science education.

MAXINE DUNFEE

Rethinking Objectives for Science Education in the Elementary School

WHEN the forerunner of this booklet was published in May 1957, curriculum makers and teachers were becoming actively concerned about the teaching of science in the elementary school, although research was scattered and results were far from definitive. In the years since, world events and national needs have served to accelerate interest to such an extent that, in contrast to the situation more than ten years ago, research is going forward on many fronts and may be characterized as extensive. In fact, it is practically impossible to keep abreast of the investigations currently being carried out by degree candidates, elementary school systems, and various university and national groups.

This high interest not only on the part of educators, but perhaps more significantly among scientists themselves, suggests the appropriateness of a study of the objectives for teaching science in the elementary school. Have the purposes for science instruction changed with the changing needs of society?

Children of today live in a scientific world. On every hand they can see the phenomena of the natural world and the operation of scientific principles. Through mass media they share instantaneously in the scientific exploits of their time. They wonder, question and explore. They bring their curiosity and concerns to the classroom. What is the school's responsibility for helping children live in their world? How can the study of science help boys and girls meet the challenges of living now and in the future? These and other questions are of concern to those who work with children and who turn to research to help them in planning for the education of their elementary school pupils.

The purposes of education stem directly from the values and ideals of the society which maintains it. We can assume that the chief purpose of education in the United States is to help children and young people acquire those understandings, attitudes, and skills which happy and useful citizens of a democratic society need, and that science education has a significant role to play in the realization of the overall purposes of education.

Historically, many groups have formulated statements of educational goals which touch upon the role of science education. Two of these, the Educational Policies Commission (57) and the Harvard Committee on General Education (89), agreed more than twenty years ago that science instruction which emphasizes throughout childhood and adolescence the development of scientific attitudes and methods of problem solving is an essential part of learning to live in a democracy. A comprehensive study of objectives in elementary education, a report by Kearney (111) which has now become a classic, identified objectives that stress learning to think scientifically, to use methods of science to solve problems of everyday living, and to draw generalizations from facts and their relationships.

A pioneer study in the development of objectives specifically for the teaching of elementary science was undertaken by Craig (38:12-13). When it became apparent to him that current practice revealed lack of organization and lack of agreement upon objectives, he set out to validate criteria for selecting objectives directed toward helping boys and girls become intelligent participants in their environment. He developed three criteria:

> 1. Certain objectives that are selected for elementary school science should conform to those scientific conceptions (a) which, when understood, greatly influence the thought reaction of the individual, (b) which have modified thinking in many fields.
>
> 2. Certain objectives that are selected for elementary school science should conform to those goals (information, skills, and habits) in science that are important because of their function in establishing health, economy, and safety in private and public life.
>
> 3. Certain objectives that are selected for elementary school science should conform to those facts, principles, generalizations, and hypotheses of science which are essential to the interpretation of the natural phenomena which commonly challenge children.

These criteria are still important in view of the fact that until very recently, at least, our elementary science programs have been based largely upon Craig's work.

Another significant approach to objectives was taken by Stratemeyer, Forkner and McKim (191) in their identification of "persistent life situations" which learners face. The authors pointed clearly to those situations, among the many life needs of children and adults, in which environmental facts and forces must be met—adjustment to climatic conditions; care, control and use of plants and animals; utilization of physical and chemical change in everyday life—and to those situations in which technological resources must be used wisely. Science education emphasizing science as technology was clearly supported by the study. McCloskey (135), who traced the development and growth of the role of science in general education, identified this emphasis upon technology as representative of a stage of science education which went beyond earlier concentration upon "nature study" (natural history) to include the application of science to daily living. Both of these approaches, however, as McCloskey pointed out, tended to ignore the underlying principles that lead to an understanding of science, principles considered so essential as the basis for curriculum development today.

Whether or not objectives for elementary science education are changing is frequently a topic of discussion among educators. Certainly, as pointed out both by Johnson (103) and Wailes (203), there are outward changes that suggest a shift in emphases in objectives. Both writers note less concentration on subject matter, more concern for the development of a variety of unstructured methods for solving problems, more concern for encouragement of inquiry than for acquisition of facts, more emphasis upon experimentation and discovery, less concern for studying science as useful technology, and greater effort to develop basic principles.

These same trends show up in Blackwood's (19:180) analysis of science education practices in American public schools in 1960-1961. Seven goals for science instruction were emphasized by more than 69 percent of the respondents:

1. Help children develop their curiosity and ask what, how, and why questions
2. Help children learn (how) to think critically
3. Teach knowledge about typical areas of science study such as weather, electricity, plant, animal life, and others
4. Help children learn concepts and ideas for interpreting their environment
5. Develop appreciations for and attitudes about the environment
6. Help children develop problem-solving skills
7. Develop responsibility for the proper use of science knowledge for the betterment of man.

To determine whether or not recent activity in elementary science is evidence of changes in science objectives, Newport (149) submitted a list of objectives formulated by Croxton (42), as representative of objectives developed prior to 1957, and a list of objectives identified by Jacobsen (100), as representative of objectives stated since 1957, and asked his subjects to estimate the date when each might have been published. Although only a limited number of teacher trainees and experienced teachers participated, almost all subjects identified the earlier Croxton list as having been written after 1957. The results of this small but intriguing study seem to indicate that differences in objectives "before and after Sputnik" may be differences not so much in intent as in semantics and that current activity in elementary science education may be evidence of dissatisfaction not so much with objectives of the past as with their implementation today.

Regardless of whether or not objectives for science education have really changed or not, there are at least two major points of attack by most of the current curriculum studies. In the long-standing controversy between content and method, present-day approaches are standing firmly for both, while interpreting these phases of science instruction in new and challenging ways.

Traditionally, science educators have been interested in scientific method and have included skills in thinking scientifically in their objectives for elementary school pupils. They made ready application to problem solving in science of the logical steps in reflective thinking, identified by Dewey (50:72)—"a felt difficulty, its location and definition, suggestion of possible solution, development by reasoning of the bearings of the suggestion, and further observation and experiment leading to its acceptance or rejection." In 1934, Curtis (45) analyzed in an informal way the steps by which scientists arrived at important discoveries, as these steps were revealed in a history of science. He developed a list of steps generally approved by a dozen scientists at a large university. More than ten years later Keeslar (112), after surveying research studies dealing with scientific method, drew up a list of steps generally associated with scientific problem solving—sensing a problem, defining a problem, and so on.

A recent study by Riggsby (171), however, reflects newer attitudes toward scientific method, once thought of as a rigidly-structured scheme for problem solving. He compared descriptions of scientific methodology found in contemporary school science textbooks with descriptions of scientific method isolated from the writings of eminent scientists and confirmed by correspondence with them. Riggsby found that textbook definitions were much more rigid than those of scientists and that the methodology of science as presented in textbooks had little of the dynamic quality inherent in methods described by scientists. In other words, Riggsby's study confirmed widespread contention that there is a variety of scientific methods rather than one scientific method, and that the processes of science are not always structured.

Currently, skills in scientific method as objectives of instruction are being thought of as skills of inquiry which the pupil may employ autonomously, empirically, and inductively in his approach to problems of science. Inquiry is considered to be open-ended and often unstructured and may or may not result in the achievement of a particular objective related to the content or ideas with which pupils are working. In short, in the inquiry process the pupil systematically gathers data about a problem, formulates hypotheses, and tests them through verbal or actual experimentation.

Studies in inquiry training by Suchman (192), which are described later in this publication, and the major items in the processes of science, defined by the National Science Teachers Association (144:21), are illustrative of the current emphasis upon methods of search as objectives of instruction:

1. Science proceeds on the assumption, based on centuries of experience, that the universe is not capricious.
2. Scientific knowledge is based on observation of samples of matter that are accessible to public investigation in contrast with purely private inspection.
3. Science proceeds in a piecemeal manner, even though it also aims at achieving a systematic and comprehensive understanding of various sectors or aspects of nature.
4. Science is not, and probably never will be, a finished enterprise, and there remains very much more to be discovered about how things in the universe behave and how they are interrelated.
5. Measurement is an important feature of most branches of modern science because the formulation as well as the establishment of laws is facilitated through the development of quantitative distinctions.

Not only are the methods of science being reinterpreted in the objectives of science for the elementary school, but also former emphasis upon basic principles of content is being reexamined with a view to producing a more science-literate group of pupils. In this view, the word "structure" is appearing frequently in current objectives, a term generally referring to the large ideas of science, the ideas to which scientists turn when faced with new problems. In other words, "structure" usually relates to the explaining principles of a discipline, the unifying ideas that keep science instruction from being a piecemeal series of isolated, disconnected units.

Current emphasis upon the development of the "structure" of science as represented in certain "bold ideas" is explored rather fully by Shamos (185). He tries to show that science instruction has failed because the "stuff" of which science is made has been largely neglected. He describes the major conceptual schemes developed by the National Science Teachers Association and illustrates these in various branches of science. While the researcher points out that there is some criticism of these statements by those who believe them to be too heavily loaded toward the physical sciences, they are reproduced here because they are an authoritative representation of a set of ideas upon which a unified science curriculum may be built (144:20).

1. All matter is composed of units called fundamental particles; under certain conditions these particles can be transformed into energy and vice versa.

2. Matter exists in the form of units which can be classified into hierarchies of organizational levels.

3. The behavior of matter in the universe can be described on a statistical basis.

4. Units of matter interact. The bases of all ordinary interactions are electromagnetic, gravitational and nuclear forces.

5. All interacting units of matter tend toward equilibrium states in which the energy content (enthalpy) is a minimum and the energy distribution (entropy) is most random. In the process of attaining equilibrium, energy transformations occur. Nevertheless, the sum of energy and matter in the universe remains constant.

6. One of the forms of energy is the motion of units of matter. Such motion is responsible for heat and temperature and for the states of matter: solid, liquid, and gaseous.

7. All matter exists in time and space and, since interactions occur among its units, matter is subject in some degree to changes with time. Such changes may occur at various rates and in various patterns.

Publication of the conceptual schemes listed above has been met with various degrees of acceptance and rejection. To Russell (176) they represent a forecast of extensive change in American education, a desirable trend toward the kind of education he believes will be extremely important twenty years in the future, when ability to deal with the world in abstract terms will be a commonplace expectancy. DeRose (48) considers the statement of conceptual schemes an important first step in sifting out basic ideas upon which unified science programs may be developed.

Glass (76), on the other hand, finds it impossible to accept the statement of conceptual schemes as the basis for organizing the study of biological sciences, nor does he see in its all-inclusiveness any practical value of planning a science curriculum. Misinterpretation and mistaken emphases are, in his opinion, all too likely. Defining a similar point of view, Ausubel (6) finds the high level of generality of the concepts incompatible with the level of sophistication and cognitive maturity of elementary and secondary school science pupils. He would also like to avoid acceptance of the misconception that the conceptual schemes can apply equally well to all sciences, especially the biological and social studies.

Fish (59) supports the premise that there is a "structure" that embraces all natural phenomena in a dynamic way and proposes that the elementary science program be organized with this structure in mind. Her point is that such unifying principles will help pupils see sense in what they are studying, will help them put details in their proper relationship, and will assist them in applying to new problem situations the principles being illustrated.

Generally speaking, modern statements of science objectives emphasize structure, process, and attitudes. Illustrative of such statements is that of the Illinois Curriculum Program (97:13), which gives the following reasons for science instruction:

1. To familiarize children with a basic body of knowledge
    a. To acquaint children with the fundamental facts and ideas of science
    b. To integrate the broad subject matter areas of science as much as possible so that the child can begin to see science in total perspective
    c. To correct common misconceptions relative to science phenomena in our environment and to combat superstition
    d. To help children understand the scientific facts and applications regarding personal health and human survival
2. To help children develop proper attitudes toward science and the world of technology
    a. To develop the attitude that, in the physical universe, nothing happens without a cause
    b. To develop an appreciation for science and its potential
    c. To develop an appreciation for the inherent limitations of science and the fact that science is not a panacea for all man's difficulties
    d. To stimulate a wholesome interest in science
3. To help children acquire the basic skills of science so they will be able to study better about, and function within, a scientific environment. These skills are:
    a. Skills in making observations
    b. Skills in making comparisons
    c. Skills in making relevant distinctions
    d. Skills in critical thinking

e. Skills in experimentation

f. Skills in investigation.

For comparison and contrast, a formal statement of objectives for elementary science as viewed by the Commission on Science of the American Association for the Advancement of Science and written by Kessen (115) must be included. This statement gives a clear definition of what this group believes to be the central purpose of science education "to awaken in the child, whether or not he will become a professional scientist, a sense of the joy, the excitement, and the intellectual power of science." Kessen's article develops rather fully the goals of inquiry, scientific attitude, and scientific knowledge, with special emphasis upon teaching pupils the procedures of science—teaching them to use sources of reliable information, to compare phenomena, to build systems of classification, to use the instruments of science, to measure, to experiment, to evaluate evidence and draw conclusions, and to communicate ideas and observations.

Such an analysis is good preparation for the elimination of nonbehavioral objectives, says Kurtz (120), who believes that answering the question, "What do I want students to do?" will help teachers see more clearly what they are trying to accomplish in elementary science. Some of these behavioral objectives require the child to classify a set of objects and to identify the basis of classification, to distinguish between observation and inference, to construct some kind of graphic representation of data, to state a prediction or inference, to design an experiment, to select proper units for measuring quantities, to order a group of objects, to demonstrate how to test a prediction, to state an interpretation of some data, and to describe an object verbally so that another can draw a picture of the object. Gagné (68) also gives special emphasis to the definition of such performance objectives as the starting point for building curriculum in elementary science.

It is clear that, although basic objectives directed towards scientific thinking, scientific attitudes, and understanding of principles that govern the natural world have been of traditional and continuing concern in science education, these goals are now being clarified in ways that make more practical sense to today's teachers and that make their realization more nearly possible now than in the past.

Reviewing and Reconstructing the Elementary Science Curriculum

A REVIEW and redefinition of objectives for any curriculum area lead inevitably to their application to existing programs to determine needs for revision or replacement. With the current emphasis upon the high priority science education should receive in the elementary school, educators and scientists have formed a partnership to search out and define the most effective framework possible for an elementary science program designed to develop structural principles, methodology and attitudes. Innovations and tryouts of innovations are the natural result of such exploration.

Several major curriculum studies have concentrated upon new directions in science education—encouraging a variety of modes of inquiry and developing various aspects of the basic principles of science through challenging and often unique content. These larger efforts have influenced both groups and individuals to reexamine the content and methods now in use and to propose improvements; and these efforts, too, have resulted in a variety of studies.

A major study dealing with these concerns, the University of California Elementary School Science Project (Department of Botany, University of California, Berkeley, California), supported by the National Science Foundation, has been reported by Scott (181). The purpose of the research has been to determine what science concepts elementary school children can learn, to find out whether they can use basic methods of science, to determine whether a curriculum can be built around these concepts and methods, and to examine the possible contributions of university scientists to such an undertaking.

The procedure has been to prepare instructional units built on fundamental concepts, units which would foster inductive thinking—units concerned with force, physiology of the human body, animal coloration, coordinates, structure and properties of matter, wave motion, plants and their development, population dynamics, and the like, and then to test the materials with a variety of evaluation techniques in a number of classrooms. The project has shown that children can use basic methods of science in coming to understand fundamental principles of science, and that they, as well as their parents and teachers, are enthusiastic about their learning experiences. The study has also made clear the need for imaginative instructional materials for both pupils and teachers.

The National Science Foundation is also supporting the Elementary Science Study (Educational Services, Incorporated, Box 415, Watertown, Massachusetts). Nichols (152) describes this study, designed to bring to pupils scientifically sound accounts of such challenging topics as growing seeds, small things, gases and airs, bones, batteries and bulks, kitchen physics, behavior of mealworms, and dozens of others; and to encourage the spirit of inquiry and discovery. Scientists, teachers, and curriculum directors have cooperated in institute sessions to build the materials—planning blocks of content which flow from the questions and observations of children, designing inexpensive apparatus, developing plans for teaching, and producing closely integrated loop films, motion pictures, and similar aids. Although emphasis here is not on development of a sequential program, the model units are being tested extensively in elementary classrooms.

In contrast, however, the Science Curriculum Improvement Study (Department of Physics, University of California, Berkeley, California), also supported by the National Science Foundation, is directed toward the construction of a science program based on a hierarchical arrangement of levels of abstraction; for example, first level abstractions are conceptions of matter, of living matter, of conservation of matter, and of variation in one property among similar objects. Second level abstractions are conceptions of interactions and of relativity; third level abstractions are conceptions of energy, of equilibrium, of steady state, and of behavior, reproduction and speciation of living matter. Simpler abstractions are developed first and built upon later as higher level abstractions are introduced.

Units at each level of abstraction, accompanied by laboratory equipment and material kits for the entire program, will be available upon completion. Karplus (108, 109) describes the study and Karplus and Thier (110) reinforce its intent by illustrating how the methods suggested may help teachers overcome the idea that every learning experience in science must be structured so as to result in learnings that can be identified and summarized at the close of the experiment. Very recently Fletcher (63) reported current tests in SCIS schools of a biology unit for first grade, part of a program to teach children biological principles through observation and experimentation.

The University of Illinois Elementary School Science Project (805 W. Pennsylvania Avenue, Urbana, Illinois), under the direction of Atkin (5), has undertaken to assess pupil reaction to a study of certain science topics basic to modern astronomy—their interest in the content and their achievement. As in studies already mentioned, teaching units were developed with the assistance of experts—professional astronomers, in this case—and principles and methods used were those employed by modern science—the discovery of major relationships and ideas. The materials were extensively tested in classrooms, where sessions were taped for careful analysis.

There was clear evidence, in the opinion of the researcher, that pupils were both interested in and capable of comprehending content and concepts not now included in most elementary curricula. There were, however, some problems in educating teachers in the content and method of the experiment, since both are quite sophisticated; and subsequent use of the unit by teachers elsewhere has borne out the reality of these problems. However, the discovery nature of the materials used seemed to be a definite asset to teachers as they guided their pupils; and apparently pupils' success did not depend wholly upon the science background of their teachers. Other topics for study, such as running water and river development; beans and biology; motion, photographs and pendulums, are being developed in the School Science Curriculum Project, also sponsored by the University of Illinois. After trial and evaluation in selected classrooms, approximately 60 upper elementary and junior high school teachers in various parts of the United States are using and evaluating the program. There are plans for use of the new materials in teacher education as well.

Considerable interest has been shown recently in the efforts of the American Association for the Advancement of Science to give direction to new science programs. Johnson (103) reports the findings of the association's feasibility study, these findings bearing out many of the recommendations identified with others of the studies discussed here—science should be a basic part of general education for all pupils; elementary level instruction should deal with science in an organized way; there should be a clear progression in the study from grade to grade; method should stress the spirit of discovery characteristic of science; appropriate instructional materials should be prepared for teachers and pupils. In addition, the AAAS has recommended a national curriculum in science, a feature not often expressly specified, but perhaps implied, in at least some of the efforts now going forward.

Science—A Process Approach, the program developed by the AAAS Commission on Science Education (1515 Massachusetts Avenue, N.W., Washington, D. C.) and now completed for the elementary grades, places emphasis upon the skills basic to further learning in science. A series of specific lessons is planned for each grade, lessons in which children are introduced to a variety of useful science content while gaining experiences in classifying, communicating, measuring, using numbers, observing, and using space-time relationships in the primary grades; continued in the intermediate grades with emphasis upon formulating hypotheses, making operational definitions, controlling and manipulating variables, experimenting, formulating models, and interpreting data. While process is of major importance, content is presented in appropriate sequence. Gagné (68), Livermore (128), and Wallbesser (204, 205) have described various aspects of the project for publication.

Other major projects are under way in elementary science and are producing materials of various kinds and testing them in appropriate classrooms. In the Mathematics and Science Teaching Project (720 Washington Avenue, S.E., Minneapolis, Minnesota), sponsored by the University of Minnesota, kindergarten through grade two materials have been developed as part of a coordinated mathematics and science program for the elementary school. Rosenbloom (174) identifies the unifying idea of science education in this program as the study of systems—the patterns of interactions revealed as children study the characteristics of objects and classify them. Two hundred elementary teachers in cooperating schools associated with ten colleges are testing materials on such topics as objects and their properties, interactions, variation, and introduction to measurement.

The Oakleaf Individualized Elementary School Science Project (Learning Research and Development Center, University of Pittsburgh, Pittsburgh, Pennsylvania) is producing materials and curriculum designed to meet the needs of individual children and to help each to progress at his own rate (129:193-94). Another effort, the Elementary School Science Project (John K. Wood, Utah State University, Logan, Utah), is planning and developing science materials for first and second grades, stressing methods of observing changes in the characteristics of interacting objects; appropriate tests of concept development are in the process of production and trial in four classrooms in Logan, Utah (129:135-36). The Elementary Science Project (Departments of Education and Physics, Box 574, Howard University, Washington, D. C.) is designed to create a program of science experiences for disadvantaged children and to discover the usefulness of such a program in terms of helping pupils overcome social and personal handicaps and to bring about changes in behavior. Paige (158) describes this unique study in which both parents and children from economically deprived areas work in small groups of 20 families with a leader, carrying out experiments designed to help them learn to observe, to follow directions, to measure, and to apply their findings to daily living.

Special interest in developing quantitative aspects of science in the elementary school is the motivation for studies reported by Swartz (193) and developed at the State University of New York at Stony Brook. Swartz believes that, from the beginning of the elementary school, children should work with science as a discipline requiring quantitative treatment and closely tied to mathematics. A hundred units for kindergarten through grade six, distributed among standard natural science topics and designed to teach measurement, are being tried out in the elementary school. This concern for teaching estimation and measurement in elementary science has also motivated the development of appropriate units by the Webster Institute of Mathematics, Science, and Arts (Webster College, Webster Groves, Missouri), work supported in part by the Carnegie Foundation. Merrick (138) is the author of *The Shell Game,* an experience for children taken from a larger block under development at Webster College. It is a fascinating development of skills in measurement based on the familiar "candle in the jar" experiments. The suggestions for catching the interest of children and involving them in estimation and measurement are unique and delightful.

Several newly initiated studies are further examples of continuing experimental efforts. The Intermediate Science Curriculum Study (Ernest Burkham, Florida State University, Kellum Hall, Tallahassee, Florida) is a project in which individualized instruction for junior high school students emphasizes both major science concepts and the processes of science inquiry (99). Especially written materials and selected laboratory equipment develop content sequentially planned to capture the interest of these pupils and to extend their skill and knowledge.

Another study, the Longitudinal Study of Children's Experimentation and Learning of Selected Physics Principles (Arnold M. Lahti, Western Washington State College, Bellingham, Washington) is one in which children in grades one through six are designing, carrying out, and drawing conclusions from their own experiments on an individual basis (129:250). And in another, the Conceptually Oriented Program in Elementary Science (Morris H. Shamos and J. Darrell Barnard, Washington Square College, New York University, New York, New York), an elementary science sequence related to concepts of energy conservation is proposed (129:251). Major new curriculum developments are effectively summarized by Blackwood (18) who calls attention to their common features as well as their unique strategies.

State and local school systems are also engaged in some useful explorations in science curriculum improvement. The Arlington County (Virginia) K-12 Curriculum Development Project (4751-25th Street, North Arlington, Virginia) is in the process of developing elementary materials introducing children to living things, earth and universe, and matter and energy (129:105-07). In the Chicago public schools project, Curriculum Development of Teaching Guides for Science (228 North LaSalle Street, Chicago, Illinois), teaching guides emphasize scientific concepts useful in understanding the natural environment, skills of problem solving, and habits of scientific thinking, and suggest learning experiences to achieve these emphases. The guides will undergo revisions after trial use (129:124-28). Resource units for a K-12 Science Design (301 West Amador Avenue, Las Cruces, New Mexico) are described by Taylor (194), director of the project.

A newly initiated effort, the Elementary School Science Planning Project (Leonard Rieser, Norwich School, Norwich, Vermont) proposes to devise and test for effectiveness a composite of materials drawn from several of the large projects described above (129:250). This development has potential for helping other schools draw upon, rather than accept exactly as planned, one or more of the national programs prominent in current curriculum developments.

The curriculum developments briefly summarized here are illustrative of the widespread innovative activity that is stirring the elementary science field. In 1963, in an effort designed to survey work in progress around the country, a committee of the National Science Teachers Association gathered data from 500 persons who had been identified as associated with active science programs. A synthesis of this information has been reported by Zafforoni (219). The publication opens by emphasizing the criteria appropriate to the evaluation of elementary school science programs. These criteria are included here for their obvious usefulness to the reader who may be overwhelmed by the quantity of activity being currently reported, as well as concerned about its quality (219:3-4).

1. Is the science program and its activities clearly aimed at developing an attitude of inquiry and encouraging its carryover to other subjects?
2. Have qualified consultants helped to identify the subject matter and the teaching methods pertinent to the needs of children and society?
3. Do classroom activities show promise for developing the highest quality of learning in science of which the children are capable?

4. Do programs show a sequence of learning activities that develop both the product and the processes of learning?

5. Do programs recognize and apply present-day knowledge of the behavioral patterns and growth processes of children?

6. Are appropriate facilities being made available for children to study science?

7. Are sufficient time allotments made for science study? Are enough teachers assigned to science teaching and are they adequately prepared for this assignment?

Recently the Science Teaching Center (University of Maryland, College Park, Maryland) has undertaken the tremendous task of publishing in easy-reference outline form current information about all major ongoing projects (129). Such a publication is invaluable at this time.

While it may appear that current curriculum studies are moving in a variety of directions with few of them committed to developing a complete curriculum for the elementary school, it is nevertheless significant that so many groups of educators and scientists are involved in curriculum experimentation. Divergent as the studies may seem, there are certain striking features common to many. In a survey of these curriculum projects in elementary science, Clinchy (34) identifies certain important trends:

1. The significant involvement of scientists in revision of the elementary science curriculum
2. The widespread support for financing and trying out the new proposals
3. The emphasis upon processes of science
4. The unique and sometimes unusual approach to content
5. The necessity for production of materials appropriate to the new content
6. The necessity for educating teachers in the development of new programs
7. The tentative and experimental nature of the proposals.

As the general school system attempts to make use of the results of experimental programs, Ausubel (7) suggests several psychological factors that should be considered when curriculum changes are being planned. He warns that the elementary school child is completely dependent upon his own present or recent experiences for an "understanding or manipulation of rational propositions"; consequently, general laws of science may have little meaning, and abstract principles of inquiry may have less meaning than concrete-empirical explanation. Furthermore, he warns that overemphasis upon developing inquiry skills may leave pupils insufficient time to learn the content of science; for example, a child might be quite skillful at problem solving but unable to solve problems involving applications of principles to new content. Lastly, over-concern for pupil self-discovery may be time consuming and inefficient; that is to say, since the child cannot be engaged full-time in search and discovery, his efforts to discover must be based on content which he has learned. When Ausubel proposes that children learn an organized body of knowledge as an explicit end in itself, he seems to part company at least in emphasis with Suchman and others who emphasize ability to inquire and to discover autonomously more than they emphasize content.

Because the multiplicity of efforts may be confusing to those on the outside who are interested in curriculum development, Frazier (64) suggests that it is important to recognize the phases of curriculum improvement as a process taking place in six steps: (a) defining purposes; (b) identifying structure; (c) selecting content; (d) collecting resources; (e) teaching the new program; and (f) evaluating improvement. He points out also that these efforts must be supported by at least three other services —actual curriculum development based on the above steps, in-service education, and supervision and consultation. While a number of school systems have come into contact with new programs through participation, often without fully accepting the program as their own, Frazier suggests the advisability of new efforts to help school systems draw what may be good from multiple sources of new content and instructional materials; then each school system's program can be truly its own and not a copy of something developed elsewhere.

Investigating Children's Science Learning

ALTHOUGH there is much yet to be discovered about children's learning of science, research of the recent past and that which is going on in current curriculum development is revealing more and more about factors that affect learning. Two facets—children's science interest and their concept development—seem to have attracted the attention of educators and to have become the focus of considerable research.

Children's Interest in Science

The vital role of interest and interests is readily accepted by those who are developing new science programs for children, and, although in general the point of departure in planning these programs has not been the expressed interests of children, selection of content and methods has been undertaken to stimulate and maintain the interest of the learner.

The continuing significance of the relationship between interest and achievement suggests a review of some early as well as some more recent studies of pupils' interest in science and the role of interest in motivation. Such a survey may be serviceable to those who are responsible for selection of curricular topics or problems used to illustrate major conceptual themes or principles in science.

When expressed interests of children had greater priority with educators than they seem to have at present, Baker (9) asked children in grades three to six to record the questions they most wanted to have answered. An analysis of these questions revealed a depth of concern for the things of the natural and social world that few teachers may have suspected. The range of "hows" and "whys" left little doubt about children's quest for science information. The piling up of questions in such areas as animal life, the earth, plant life, energy, the human body, and astronomy gave a measure of direction to those who were planning science programs for children. Drill's (53) analysis of free discussion periods revealed that children talk about science phenomena frequently, showing special interest in plants, animals, machines, or other aspects of the physical environment. She concluded that boys throughout the elementary school show greater interest in science than do girls.

Morton (142) used questionnaires, interviews, and analysis of children's choices of textbook topics and pamphlets to determine the science interests of a group of sixth grade pupils. Although he was unable to rank the interests, all techniques used revealed high interest in ancient plants and animals, with other interests ranging through astronomy, magnetism, electricity, and earth and its surface. First grade pupils studied by Smith (187) seemed to be most interested in weather, animals, air, aviation, and seeds. In 1956 Young (217) explored the science interests of a selected group of fourth grade children. Through check-lists of films they would like to see, questions they would like answered, interest inventories, and pupil and parent questionnaires, she discovered greatest interest in the universe and strong interest in animals, earth, human growth, and weather. While group interests were stable, individual variation within each group was great. Children's expressed interests coincided with those they revealed through the various instruments, and parents' estimates of children's interests were generally accurate except in the area of human development where parents did not usually suspect the children's high concern.

As previously suggested, the science interests of children do not seem to be of greatest concern in recent curriculum developments; the trend appears to be away from a child-centered to a content-and-principle-centered science program. This does not mean, however, that children's interests can be completely ignored or that they are of no importance. While recent studies in this area are limited, several have significance for teachers. Perrodin (160) worked with 554 children in fourth, sixth, and eighth grades in an effort to determine the interests of these children, whether or not these interests correspond to the course of study, and whether or not interests change as pupils move through the elementary school. Perrodin used an unusual technique—a projective-type instrument containing 20 sentence fragments which pupils were asked to complete with the first thought that came to mind. It is most interesting that in an age of space exploration, children's favorite area of study was health, safety, and the human body; the study of living things was popular, with girls more interested in this area than boys. Fewer pupils listed favorite units in the physical sciences than in the biological, with boys' interests exceeding girls' in this area.

Bowen (22) examined the science interests of boys and girls through the medium of the science fair. In 22 exhibitions, projects in physical science were overwhelmingly chosen by boys; in only one were there more girls than boys presenting exhibits in the physical sciences; in only five did more boys than girls choose the biological sciences. Bowen believes that sex differences in attitudes exist and do affect the quality and quantity of science taught in the schools; he also suggests that the sex and science interests and attitudes of teachers play an important part in the values of their pupils. The findings of both Bowen and Perrodin are in contrast to those in an earlier study by Fitzpatrick (62), who found no marked preferences for biological or physical sciences among boys and girls. On the other hand, Fitzpatrick's conclusion, after examining pupil testimony about their science interests, is still worth heeding: there is evidence that children's interests are not always long lasting or consistently patterned for various age groups.

A now-classic study by Jersild and Tasch (101:71-83) gave science teachers food for thought by turning up evidence that children, when asked what they liked or disliked about school, did not mention either favorably or unfavorably, the study of science. Some conclusions from this comprehensive study are specially significant, even though they do not mention science specifically.

1. There is a highly developed self-interest in children's ideas about life and the world in which they live.
2. There is much variation in interests from school to school and from class to class.
3. There is evidence that children's interests are for the most part learned.
4. There is an apparent discrepancy between children's interests and needs.
5. Adults influence greatly the interests of children.
6. Many children are apparently occupied in activities that are not interesting to them.
7. Many children are not realizing their full potential.

In the present decade several studies throw some light upon children's interest in science. Greenblatt (78) investigated the relative popularity of certain school subjects in the third, fourth, and fifth grades, relationships of these preferences to sex, intelligence and achievement, and similarity of children's and teachers' choices. In this study science occupied a middle position, being less popular than art, reading, and arithmetic, and more popular than writing, language, and health. Sex differences were evident—boys showed a significant preference for science, girls for music; there was some indication that selections of teachers and pupils correspond, particularly with pupils of higher intelligence. In this study, as in that by Jersild and Tasch, science occupied an intermediate position—neither favored nor disliked.

To test the influence of new curriculum materials on the attitudes of fifth grade pupils was the task undertaken by Lowery (131). Twelve fifth grade classes were selected from three socioeconomic areas and half were taught one of the units developed in the University of California Elementary School Science Project. Prior to the study, the attitudes of all groups toward science were examined, and following the study a similar analysis was made. Pupils in experimental groups gave evidence of more positive attitudes toward science after their study. Middle- and lower-area pupils who initially indicated a dislike for science because of reading difficulty also improved in attitude. If such studies of attitudes are made in connection with the many new curriculum projects being developed, the findings can certainly tell researchers and teachers something significant about the values of these projects when practical classroom application is made of their materials and techniques.

Kahn (106) experimented to determine the effect of a current events approach to science upon the attitudes toward science of seventh- and eighth-grade boys. Experimental groups, with no loss in achievement, were significantly higher in desire to try things out experimentally, in desire to observe carefully, in rejection of superstition, and in willingness to change an opinion as well as in unwillingness to base conclusions on too little data. According to Moore (141), there is some evidence, based on a study of 387 high school finalists in the Thirteenth National Science Fair, that science interests peak at age 12. In a concern for vocational choices, Gaetano (66) studied elementary science textbooks from six publishers to determine the distribution of male and female figures in the illustrations. In the primary textbooks, she found no significant difference in the prevalence of male and female figures; but in 16 of the 18 intermediate books male figures predominated to a significant degree. The researcher raises the question of the possible effect of this use of male figures in illustrations on girls' choice of science as an acceptable career.

Hardin (85) was interested in identifying the dimensions of pupils' interest in science. She learned that science interest for intermediate grade pupils is "multidimensional"—including work with physical science materials, group activity, investigation of earth sciences, interest in scientific contribution, exploration of the animal world, cultivation of plant life, participation in individual and at home interests, attendance at movies, and the interest of parents. Pupils in the study also were aware of the interest of their teachers and associated this interest with a positive classroom atmosphere.

Johns' (102) study of 52 pupils of high intelligence convinced him that science interest can be measured by means of tests which are not "fakable" and that this measure of science interest can be a predictor of achievement. Like Hardin, Johns concluded that science interest has more than a single dimension.

Because of the traditionally-held view of the close relationship of interest to motivation and achievement, ascertaining the elements of science that create pupil interest must continue to be a major effort in elementary science education.

Development of Science Concepts

New programs in science, stressing the teaching of basic concepts and principles of science through methods of inquiry, raise serious questions about children's ability to develop concepts and about the process of concept development. A definitive though early study in this area is that by Deutsche (49), whose thorough analysis of children's cause and effect responses to simple experiments in physical science revealed that boys and girls gradually progress with advancing age in their ability to see causal relationships and that many very young children show surprising ability along this line. Oakes (155) found corroborative evidence that children explain phenomena in naturalistic terms, their responses differing from those of adults only in quantitative terms.

Other studies have been directed toward determining the level of difficulty of certain science concepts and principles. In 1941 Bailey (8) attempted to ascertain whether or not upper grade children were able to understand certain science concepts related to power. He concluded that sixth-grade children were not generally competent in this area, whereas bright junior-high pupils were very successful in this field. McCollum (136), too, studied the relationships between subject matter and maturity and found that correct explanations of science phenomena came with increasing maturity. McCollum recommended that the grading of science content could well be based on the kind of pupil interview technique used in his study. Oxendine (157) worked with a group of fourth-grade children and a group of sixth-grade children to determine the mental age at which a teacher could expect maximum success with a given science principle.

The idea that "little" children can deal only with "little" ideas—that principles of science are beyond them—has been investigated continuously for 20 years or more. Investigators have found that the thinking of young children can be quite mature and that their ability to generalize is dependent upon the meaningfulness of their experiences. Haupt (92) reports that even first-grade children hinted at a cause and effect relationship between rocks, mountains and stones, and the appearance of the face on the moon. It would be interesting to repeat Haupt's study today to see how children would respond to such situations as a result of their contact with new knowledge about space and space travel. In a study of children's understandings about magnetism, Haupt (91) also concluded that some children of the lower grades had "attained to concepts" that were equivalent in complexity and maturity to the ones from children in higher grades.

Navarra (146), whose classic study was of a single child over a considerable period of time, believes that many science learnings take place before the child attains school age and that the child's thinking and approach to solutions of problems can be quite scientific. Oakes (155) found no evidence to support the contention that there is a definite state in a child's thinking which is characteristic of a given age. He reported that types of answers to questions were influenced more by the nature of the problem, the wording of the question, the children's experimental background and vocabulary than by any mental structure for a given age.

Classic among studies of children's concepts are those carried on by Piaget. Using highly refined techniques of pure observation in a clinical setting, he has compiled an extensive body of information about the child's concept of his world (163) and of physical causality (162) that is invaluable to those who plan science experiences for elementary children. Piaget and his associates have been able to define with considerable authority the mental ages at which children's original convictions about particular phenomena, unadulterated by direct teaching, represent various stages of development. The relationship of this cognitive development of learning has been explored by Piaget (161) in a rather recent issue of a research journal in the teaching of science. Stendler (188) has also illumined the relationship of Piaget's developmental approach to the teaching of science in the elementary school.

Stimulated by the challenge of such studies, other researchers are following their own avenues to knowledge of children's learning of concepts. Vygotsky (202) has reviewed several studies in this area of concern, concluding that understanding and assimilating content are only part of the process of learning a science concept—the internal development of a concept in the child's consciousness goes beyond the initial learning of information, with classroom instruction usually preceding this development.

Butts (26) tested the assertion that once the child is given the proper environment to perceive and then given free opportunity to experience certain perceptions and to merge these perceptions into concepts, meaningful concept development will result. He found that self-discovery was effective only when teacher direction focused attention on the relationships involved. This study casts some doubt upon the theory that independent manipulation of data alone is sufficient for concept develoment.

The relationship of the mental ability and learning of first grade children to science concept development was the subject of a study by Weaver and Coleman (209). They sought to discover the extent to which primary mental abilities are a function of concept development under a problem-solving approach to science teaching. The study documented the fact that children in the first grade can be taught to develop concepts which are significant and meaningful to them, that children with average or below average mental ability can deal with and develop major concepts of science, that problem-solving methods contribute to children's success in concept development. Such a study as this supports the current emphasis upon the teaching of science concepts from the earliest years of the elementary school.

Pollack (167) designed a study to consider the usefulness of scores on tests of intelligence, of reading, and of science knowledge as predictors of levels of concept development in terms of a hierarchy of understandings defined as knowledge, comprehension, and application. Although the researcher expressed some doubt about the effectiveness of his techniques, the study nevertheless seemed to indicate that knowledge of subject matter was a better predictor of behavior in comprehension and application than scores in reading or intelligence.

After 12 weeks of inquiry training, 200 children ten and eleven years of age were tested by Scott (182) to determine the relationship of inductive reasoning and cognitive styles in categorization behavior to science concept achievement. Scott found that in the ten-year range science concept development seemed to be related to inductive reasoning and in the eleven-year range to categorization behavior. In inductive reasoning ten-year-old girls appeared to be superior to boys of that age, and eleven-year-old children as a group seemed superior to ten-year-olds. The report describes the tests used and suggests the usefulness of such instruments in collecting data about pupils prior to grouping them for activities designed to develop science concepts.

In a more recent study Scott (183) sought to determine the relationship of the strategy of inquiry to children's styles of categorization. Three hundred Detroit children in grades four, five, and six were taught a series of lessons emphasizing 15 science concepts, five at each level. Half the children were taught by the Detroit inquiry process, and the others in conventional ways. All subjects were given a special test of categorization tasks at the close of the period. In grade four, pupils in the inquiry group were less likely than those in the conventional groups to categorize pictures on the basis of use or function. In grade five, girls shifted stimuli and methods of categorization more easily than boys. In grade six, inquiry groups classified items on the basis of "manifest details and inferred attributes" more so than conventionally taught pupils. In general, pupils in inquiry groups were more flexible in their categorization behavior than were the control subjects.

Anderson (4) worked with pupils in grades three, four, five, and six to determine whether or not they could formulate mental models to explain natural phenomena. The teacher performed five demonstrations of phenomena with water. The children were asked to form a mental model to explain what water is like so that the demonstrated events happen. Responses from 192 subjects were categorized as atomistic, non-atomistic, magical and animistic, and as no explanation. As a result of finding that his subjects were able to form mental models and that their skill increased with ability and age, the researcher felt justified in defending the feasibility of developing science programs designed to assist in the formation of mental models.

Hill (96), also studying children's perceptions of science phenomena, found that depth of understanding increased with experience, although no precise level could be identified for all pupils at any one level; and that acquisition of knowledge modified children's understanding. The study reinforces the importance of assessing each child's level of development and of evaluating his understanding in terms of individual rather than group progress.

While the nature and process of concept development have had the attention of some researchers, others have been particularly interested in pupils' ability to acquire specific concepts related to various facets of science content.

A first grade class of 27 six- and seven-year-old pupils were subjects of a study by Yuckenberg (218), designed to learn what preinstructional knowledge the children had of certain concepts of the sun, moon, day and night, and gravity and to find a basis upon which plans might be laid for further development of these concepts. She discovered that these children's concepts of astronomy, although faulty, were similar to those of many adults and that their interest suggested readiness for further development of these concepts in the first grade.

After interviewing 72 pupils randomly selected from lower elementary classrooms to determine their concepts of certain natural phenomena, McNeil and Keislar (137) also experimented with first-grade children to test their ability to form and use certain molecular concepts.

After special instruction, a small number of first-grade children were asked questions requiring multiple-choice responses to situations in which they were to explain evaporation and condensation, clouding mirrors, boiling water, forming dew, etc. Responses were categorized as concrete and functional, animistic and religious, and abstract, and as failure to respond. There seemed to be evidence that with appropriate instruction first-grade pupils could correctly answer questions about molecular theory.

Also using kinetic-molecular motion as the content, Ulrich (200) taught an especially planned series of demonstrations to 414 pupils, starting with the sixth grade and moving down into the third. Testing pupil comprehension with an original test, included in his report, Ulrich concluded that a mental age of 11.5 was the practical cutoff point and 6.6 the reading level below which teaching the concept would not be profitable. In a study of the molecular or kinetic theory of heat, Harris (87) attempted to determine the ability of fourth-, fifth-, and sixth-grade pupils to understand the concept. Taped lessons eliminated the teacher variable in the study. Results in this study led Harris to conclude that grade placement of the content at fourth grade level was inappropriate.

With a somewhat like interest, Inbody (98) investigated kindergarten children's understanding of selected physical phenomena and the appropriateness of typical instructional experiences provided for first-grade children. Basing his demonstration-interview technique on 16 physical phenomena selected from first- and second-grade books of eight current elementary science series, the researcher interviewed his subjects individually and taped the conversations. Although several concepts were too difficult for the kindergarten children, their understanding of at least three—dealing with the ideas that rain is water, that wind can do work, and that sun and wind speed evaporation—was such that further instruction would have been a waste of time. In fact, the explanations given by five- and six-year-olds seemed to the researcher to be those typical of Piaget's seven- and eight-year-olds. Other results were quite similar to those of related studies—there were no consistent differences in the types of explanations given by boys and by girls, but greater maturity produced more sophisticated explanations. The detailed findings of the study offer interesting specific evidence about children's understandings of all the concepts dealt with in the study.

What concepts of death should be taught to elementary school children has always been an intriguing question, although little research has been developed in this area of content. Hair (82) surveyed the limited research and then set about finding out from scientists what ideas of death in relation to plants and lower forms of animal life ought to be understood by adults. Although she felt that her results did not yield a completely valid statement, there were some agreements on a limited number of understandings from which educators might well take some cues in developing concepts, in the science classroom, of death.

Neuberger (148) was interested in an equally profound concept in his study to discover ways in which ten- and eleven-year-old children related to the nature, origin, perpetuation, and controlled direction of change in living things. He found that none of the elementary textbooks, teacher guides, and teacher-preparation plans which he studied included the theory of organic evolution; that, while children had a general awareness that variation is common to all living things, instruction increased pupil awareness of change; and that usually children employed the same mechanics to convey social change that they used in responses to questions about organic change.

Kerns (114) attempted to measure differences of comprehension of 20 selected science words among elementary school pupils in Colorado. Marked increase of understanding was shown as grade levels increased; there were no significant differences between groups with and without formal science instruction; girls showed their best comprehension of words from the biological sciences. The study pointed up the importance of planning curriculum which provides for continuous development of concepts and which takes into account the facts that children often find areas of science interesting and important before these areas become a part of formal instruction and that their ideas of what is important may not coincide with the ideas of adults.

A dissertation by Dennis (47) compared the performance of sixth grade graduates and selected civic club members on a test of information about outer space. Statistics indicated that, although the adults often performed at a more mature level, the students' performance compared favorably with that of the adult subjects. For example, about one-fourth of the students scored higher than one-fourth of the adults; approximately 3 percent of the students scored higher than 75 percent of the adults; one out of every eight children scored higher than the average of the group of adults; and approximately 5 percent of the children scored higher than the average score of the men who had done postgraduate work in college. The relatively small differences in performance between the children and the adult groups raise some questions about the quality of science instruction the participants had received.

What these studies have to say about children's development of concepts in science, while not entirely clear or consistent, does nevertheless point to certain recurring findings. It appears that concept development is not simply a matter of acquiring information nor a matter of attaining a certain maturity, though knowledge and maturity undoubtedly play their part. The essential role of experience in concept development and the feasibility of instruction focused directly upon concept development are both finding support in current studies.

In a period such as the present when emphasis upon science is increasing, when children are continually exposed to news of scientific events, when there is pressure to teach more science to children at an earlier age, there is a likelihood that adult expectations of children's science understanding and performance will rise. In a recent attempt to discover whether or not children in truth have rather mature explanations for things of science that happen around them, Joyce and his associates (105) analyzed the written protocols which represented children's attempts to explain events in the domain of science. He found that their responses to simple demonstrations were generally inadequate explanations, that they used terms in incorrect or inappropriate ways, that they did not try to guess or hypothesize, that they sought information which they thought had been withheld rather than seeking out a principle or generalization which would explain the event. In only one instance—the well-known demonstrations of the candle in the jar—were explanations clever and logical! These findings caused Joyce to issue a warning that new programs should make sure of the conceptual levels to which pupils do and do not respond and should be sure that children are developing the big ideas of science progressively level by level with ample opportunity to have experiences that will lead to real understanding.

Focusing Upon Teaching and Evaluation in Elementary Science

NO SCIENCE program, however well conceived, and organized, no matter how firmly based on opinions of experts and knowledge about children, can be more successful than its implementation in the classroom. In the mediation between program and learner, the teacher occupies a critical place. How his group is organized for instruction, how he teaches science, and how he evaluates to determine the results of his efforts become the focus of concern.

Individual Differences

With current interest in various ways of meeting individual differences receiving attention in all areas of the curriculum, science, of course, is not an exception. Ability grouping is one approach to the problem of meeting the wide range of abilities found in the usual age-level group of pupils.

Although many schools are experimenting with various ways of grouping pupils, data supporting such practices are not extensive. A few recent studies have attempted to throw some light on the values of certain grouping practices in elementary science. Becker (12) analyzed the science and mathematics achievement of 235 gifted sixth-grade children from 17 elementary schools in central and western New York who were enrolled in segregated, partially segregated, and nonsegregated classes. He found that these gifted children did not achieve significantly more when placed in special groups. Bicak (16) worked with 75 eighth-grade pupils who were placed in one of three kinds of groups—high homogeneous, heterogeneous, and low homogeneous. Content for all groups was the same with enrichment opportunities available for all. In this limited study he found no significant differences in the overall achievement or in the response behavior of the three groups. Platz (166) compared academic achievement, teacher ratings of classroom performance, and office referrals of ninth-grade general science students taught in ability groups with those who were not so grouped. He concluded that ability groups were more effective than ungrouped classes for below average achievers, but found no other significant differences in their favor in relation to achievement and teacher ratings. On the other hand, the data suggested that behavior problems that required office referral arose more frequently in the ability groups.

Montean (140) reported on some aspects of the Dual Progress Plan as developed in the West Irondequoit Central School District, Irondequoit, New York. Self-contained fifth- and sixth-grade classes were reorganized to utilize specialized teachers, teacher teamwork, and nongraded grouping for science instruction. The plan provided for pupils to move through ten units of work at any one of three levels of detail and repetition. Ninety percent of the 810 pupils who participated in the plan in 1963 approved it, and 97 percent of the teachers favored the plan.

Cunningham (44) reports another study in which the Dual Progress Plan has served as the basis for science instruction in the Fairview Schools, Skokie, Illinois. Here pupils are taught on a nongraded basis, the focus of their instruction being a sequence of laboratory experiences in which factual knowledge sequences correspond directly to the process skills. Pupils are grouped on the basis of ability to advance further in science; their activities are individualized but structured to permit each to move ahead at his own pace; instruction is guided by science specialists. Teacher judgments and practical examinations have provided evidence of the value of the plan to the present; and there are plans for the gathering of data which can be subjected to statistical treatment. The goal of the Dual Progress Plan in general is to determine by research whether nongraded grouping in science, and in certain other subjects, is better for the intellectual growth and emotional needs of children than the usual grade-level grouping (189).

Grouping children for better science instruction naturally requires alteration of program content and method to fit their special needs. Cressman (40) studied the possibilities of teaching general science to 172 fourth-grade boys and girls of above average intelligence. The course content was drawn from physics, chemistry, biology, earth science and astronomy, content which followed quite closely that recommended for junior-high school students in the state of New York. The level of succcess of these pupils was so high that the researcher concluded that for this type of pupil delaying such content until the junior-high school level would be a waste of time. The fact that they did much better work than an average ninth-grade group taking the same tests led Cressman to observe that for these pupils the usual junior-high program would have been totally unsuitable by the time they reached these higher grade levels. In other words, attention must be given to curriculum content in terms of the pupils being taught rather than in terms of some predetermined grade placement.

Throughout the country there are numerous plans on trial for organizing instruction to meet the individual needs of learners. Certainly there is growing recognition that not all teachers can be well-prepared to teach all the elementary school subjects and there has long been awareness that it is fruitless to treat all children in a group—even in ability groups—as though they were capable of the same successes. If the current experimentation results in clear-cut evidence to support one or more plans of differentiated instruction, such findings will be received with keen interest.

Learning Experiences

In all current efforts to help children develop appropriate science concepts through methods of inquiry, learning experiences have received concentrated attention. Recognizing that there are various avenues to learning, scientists and educators are complementing, if not supplanting, the conventional and long-used expository approach to science instruction by a variety of opportunities for learning experiences each with its special values and functions.

Pupil participation in planning and developing their own learning experiences is supported by several studies. Barnard and Robertson (11) found that study guides developed by pupils under the guidance of their teachers were more effective than teacher-prepared guides in helping children react successfully to both immediate and delayed tests of scientific attitudes, problem solving, and application of science generalizations. Krause (118) found that children who constructed their own tests of science content not only preferred that approach but actually were superior in their ability to respond later to a teacher-made test.

Both Clark (33) and Curtis (46) found that the school excursion extended pupil interest and enriched pupil learning about the problem under consideration. Greene (79) concluded, after a study of the use of dramatic and non-dramatic methods in teaching science to fifth-grade children, that dramatic methods increased children's interest in certain science content and that in some types of dramatic presentation there was gain in factual learning, especially when children wrote their own plays. Camping experiences as sources of learning about the natural sciences were the subject of investigation by Pike (164); his report suggests criteria for selection of such experiences and indicates that scientists and camp authorities agreed more closely on appropriate experiences for pupils than did science educators.

More recently Harris (88) experimented with the usefulness of drawings in learning science concepts. In a study designed primarily for the purpose of analyzing the problem-solving behavior of sixth-grade children, one of his experimental groups was given practice in drawing science concepts in tangible form. He concluded that instruction in science which included drawing was not significantly related to growth in ability to learn and to use these concepts in problem-solving situations. Such investigations as this one are profitable in helping to determine whether or not techniques used in science instruction are truly productive of learning.

Other studies have pointed out the need for more direct learning experiences in science. Hill's study (95) of children's contributions to science discussion led to the conclusion that more time should be allowed in all grades for investigating, for discussing, and for sharing ideas, if pupils are to grow in ability to question, identify, speculate, recognize relationships, and draw conclusions. Haupt (90) found that differences among children in ability to generalize depended upon the number of science concepts associated and the number and immediacy of the experiences involved in the development of the concepts. At about the same time Croxton (41), in his analysis of pupils' ability to generalize, concluded that pupils who were unable to make generalizations from science content may not have lacked ability to generalize but may have had insufficient experiences with the content as a basis for generalization.

A study by Eaton (56) casts an interesting sidelight on the significance of experiences in the learning of science. The study was primarily an investigation of the relationship to achievement in astronomy of three factors—number of questions, activities, and incongruities—contained in printed materials used by sixth-grade pupils. The result most pertinent to the present discussion was the finding that only one factor, number of activities, when varied in frequency, produced significant differences in test scores for the total sample and for subgroups of boys and girls; each group achieved its highest scores when studying from materials containing the greatest number of activities. Questions incorporated in the reading material did not appear to produce optimal learnings, while the role of incongruities was not clear though perhaps of some consequence. Eaton's study also suggests that reading to acquire information, one of the primary routes to science knowledge, should be complemented by many other kinds of experiences.

Roossinck (173), pursuing the idea that reading is used not only by elementary school pupils but also by scientists as a source of useful knowledge, investigated the reading methods used by scientists in order to compare these with methods used by children. Using results of a study of children's reading in science by Shores (186), Roossinck drew his comparison between their behaviors and those of 48 scientists when reading science material to understand the main idea and to relate facts and ideas in sequence. The scientists differed in their habits from what children actually did and from what children thought ideal readers would do. The study indicated that the procedures used in fast reading, skimming, and rereading for varying purposes were not common to children, who tended to read every word of the content and usually to vocalize what they had read.

Koester (116), also interested in the relationship of reading to purposes for reading, used two equated groups of sixth-grade pupils in a study to determine the relationship of measures of ability to read expository material (comprehension and rate) and measures of purposeful reading for problem solving. Each group of pupils was given two science passages a day for ten days; the passages described how to perform an experiment and an explanation of how the phenomenon occurred. The first group read for experiment directions; the second group read for the explanation. Results of the study indicated that purpose did not affect the rate of initial reading time; that fast readers were not necessarily the best in comprehension; that high science achievers achieved best in purposeful reading but not in rate of reading; that those who read fast for one purpose may not have read fast for another; and that reading behaviors were definitely influenced by purpose. Such studies as these by Roossinck and Koester point toward the significance of reading in science and toward the need for giving more attention in science programs to the development of reading behaviors adapted to the efficient extracting of data from printed materials.

Stone (190) was interested in finding out whether or not there are patterns of criteria by which elementary and secondary school teachers judge elementary science experiences. The researcher thought the findings would show to what extent elementary and secondary teachers share common goals and common ideas of methodology. She discovered that there were no significant differences between the two groups of teachers with regard to the intensity with which they used the criteria in judging science experiences. The two groups seemed to emphasize such outcomes as critical thinking and subject matter mastery about equally. It would appear that when the two groups find it difficult to cooperate in curriculum development their failure is not because of differences in basic goals and ideas about teaching.

Inquiry and Discovery Through Experimenting

In spite of continued interest in the variety of learning experiences touched upon in the studies reported above, by far the most challenging efforts are those that attempt to provide for pupil experiences in the processes of science. The theory is simply that when pupils behave (at their level of development, of course) as we may expect scientists to behave, they are experiencing science rather than just learning about science; they are involved in the development of principles and generalizations, rather than learning them through reading or expository methods.

Of all the studies devoted to the process aspect of experiencing in science, none has stirred more interest perhaps than that by Suchman (192). Whether or not skill in inquiry can be taught to elementary school children, using science as the content vehicle, became his problem. He believed that pupils could be taught to attack, through a series of "yes" or "no" questions, a scientific problem posed by a science demonstration shown without comment on film. Pupils were trained to formulate questions to determine the parameters of the situation viewed, to determine the relevance of certain conditions, and to verbally experiment to test hypotheses. Suchman concluded that fifth-grade pupils can improve their skills in inquiry and become more productive in their use of questions; as they progress, they make fewer unrelated assumptions; perform more controlled experiments during the inquiry period; and become able to transfer their strategies to new problem situations. On the other hand, the researcher concluded that pupils have little interest in the method for itself, their desire to understand the problem situation being the chief motivating factor in their performance. There were, however, increments in understanding of content as skills of inquiry developed.

The crucial role of questioning in Suchman's study is further emphasized in an investigation by Weigand (210), who recognized the significance in inquiry of the teacher's ability to determine the relevancy or irrelevancy of children's actual questions in the problem-solving process. He collected the written questions of children after they had viewed a silent color film of five science experiments. These questions were analyzed by the researcher and validated by science educators in terms of their relevancy or irrelevancy. Two groups of teacher education students were both taught by lecture, demonstration, and discussion to recognize relevant questions, but one group also worked with children's actual questions. The data revealed that the group which worked directly with children's questions benefited significantly from instruction designed to improve their recognition of relevance. To the success of inquiry, in which the teacher's appropriate response to children's questions is so critical, this study makes a significant contribution.

Butts and Jones (28) used the Suchman inquiry training technique with 109 sixth-grade children as the vehicle of instruction in a study to discover whether or not children exposed to such guidance evidenced improved problem-solving behavior; whether or not intelligence, sex, chronological age, and factual knowledge were related to improved problem-solving behavior; and whether or not children who showed improved problem-solving behavior showed meaningful concept development. Measuring for growth with their TAB Inventory of Science Processes, described later in this section, the researchers found a relationship between inquiry training and positive changes in problem-solving behavior, but no evidence to support the assertion that concept development results from inquiry training. Moreover, the data showed no relationship between the factors of intelligence, age, sex, and factual knowledge and changes in problem-solving behavior. Even though Butts and Jones raised their own questions about the limitations of their study, the research does suggest some fruitful avenues for future studies. Scott (183), in a study previously mentioned in this publication, found that inquiry training resulted in more flexible categorization of behavior among fourth-, fifth-, and sixth-grade pupils and less dependence upon commonly accepted modes of classification. The inquiry process seemed to encourage exploratory thought, creativity, and a seeing of relationships not always observable in conventional instruction.

Emphasis upon process as an objective of science instruction has given rise to various interpretations of "inquiry" and of its relationship to "discovery" and "problem solving." Some science educators see these terms as being synonymous, at least loosely so, for much the same process; others see them as related aspects of a process; others would like to discard one or more of the terms in favor of another.

Fish and Goldmark (60) describe three interpretations of "inquiry," choosing some varying points of view which are thought-provoking, even though they do not solve the dilemma surrounding attempts to define inquiry. They include a reaction to Suchman's work, which they identify as "self-directed inquiry," with its focus upon expansion and reconstruction of theories and methods concerned with a body of content; to another position taken by Ben Strasser, which treats inquiry as the expansion and reconstruction of theories and methods relating to teaching and learning, with special attention to the teacher's examination of his own behavior as a facilitator of inquiry by children; and finally to their own position, a point of view which sees inquiry as method selection with focus on discussion about which method to select. They feel that their departure continues where Suchman leaves off and at the same time requires the kind of teacher of concern to Strasser. In another article Fish and Saunders (61), by use of simulated dialogue in a study of magnetism, illustrate the broader view of inquiry consistent with the third position described above by Fish and Goldmark. In further pursuit of a definition of "inquiry" Sagl (178) in a recent article attempts to clarify the relationships that exist among inquiry, discovery, and problem solving.

Gagné (69:182-88), has shed penetrating light on efforts to define problem solving as it relates to elementary science education. He identifies a hierarchy of capabilities that are learned as the child explores the world of science, seeing them as essential to the child's success whether or not they are directly taught. The components of this hierarchy are the following:

Phase 1: Basic types of learning, including stimulus-response learning, chaining, and verbal association, in which children achieve basic relationship with their environment, both nonverbal and verbal

Phase 2: Multiple-discrimination learning in which children observe physical characteristics of objects and discriminate among them

Phase 3: Concept learning in which children use knowledge acquired in previous phases to establish generalized notions of classes of objects

Phase 4: Principle learning in which children, through experiences in classifying, measuring, space-time relationships, communicating, and inferring, come to recognize and to formulate statements of relationships (among concepts) that are of continuing applicability

Phase 5: Problem solving in which children through application of previously derived principles to new situations solve problems and emerge with higher-order principles which in turn may be applied to future problems.

In exploring the relationship of problem solving to discovery, Gagné suggests that problem solving as a method demands the discovery of principles by the pupils, although such principles need not necessarily be learned by discovery. "Problem solving, or discovery," he says, "is only the final step in a sequence of learning that extends back through many prerequisite learnings that must have preceded it in time" (69:165).

Inherent in most of the interpretations of inquiry as a mode of search is that children's thinking is not predetermined by the teacher nor is it structured to achieve results which only the teacher may have in mind. An inquiry approach to science instruction implies that there are significant problems to be solved and that freedom to examine, manipulate, and explore is an essential characteristic of children's problem-solving experiences. Whether or not and to what degree the teacher may or should structure the learning experiences is a question naturally raised by the emphasis upon creative thinking.

Barker (10) tested the idea that pupils exposed to a "discovery table" which they were encouraged to use in experimenting as much as they wished would learn a great deal of scientific information on their own. His studies of 164 children ages 10 and 11 produced evidence to support his hypothesis. On the other hand, Butts (26) concluded, after confronting intermediate grade pupils with a science phenomenon and giving them freedom to do with the experience as they wished, that while self-discovery is rewarding and motivating; it must depend upon some external direction which focuses attention on the relationships involved. Butts questions the adequacy of independent manipulation of data as being sufficient for concept development.

Hawkins (93) further examines the function of the independent manipulation of science phenomena in an hypothesis he has developed as a result of his experiences with children in the Elementary Science Study. As he sees it, schoolwork in science falls into three patterns or phases—different because of what children do in them and because of what happens, though not necessarily in an ordered way, in the classroom. He considers of prime importance the phase which he calls "messing about"—a time when children are encouraged to explore, manipulate, and try out ideas with materials and equipment provided for them. The author's work led him to the conclusion that this phase may be quite extended, over weeks if interest is high, in order to give full range to children's curiosities, the identification of problems for the more guided phases to follow—directed investigation to fit individual differences—and then a pooling of information, discussion of ideas, and extracting of generalizations.

The effects of structuring on productiveness of children's thinking were explored by Crabtree (37) in a group of 24 second-grade children studying airport and harbor activities. Two programs were developed, one in which the environment was unarranged, consisting of ambiguous materials and a few structured cues for play; the other, prior-arranged with high realism materials organized to invite certain patterns of response. The subjects were paired and grouped and both groups received both programs.

Through careful analysis of both quantitative and descriptive data, Crabtree found that divergent thinking, characterized by creativity and freedom from rigidity, occurred more abundantly in the unstructured program, and convergent thinking—accurate and well-supported responses—was more fully evident in under-structured programming. The undirected situation brought out more extensive and highly constructive sequences in play, but such responses did not increase within the permissive situation as the researcher had hypothesized. This study seemed to support the present trend toward more unstructured investigation in science rather than the step-by-step procedures laid out in earlier interpretations of scientific method, although, obviously, both convergent and divergent thinking are desirable at appropriate times.

There has been, of course, considerable interest in whether or not problem-solving methods result in greater achievement in science learning. Carpenter (31) tested textbook recitation versus problem-solving methods in teaching science to fourth-grade pupils in a situation in which roles were reversed during the study. He found that the results consistently favored the problem solving—activity type—approach to instruction. Bennett's comparison (13) of the experimental-field methods and the traditional classroom method, involving content in ecology for the seventh grade, led to the conclusion that neither approach had an advantage in producing science learning, but the researcher believed that there were other understandings and attitudes, beyond the acquisition of knowledge, arising from the field work which were not revealed by the instruments he used. Scandura (179) attempted to identify the relative value of exposition and discovery methods of instruction. His data showed that when there was adequate readiness for problem-solving methods, children solved new problems based on principles developed through problem solving. When pupils moved into problem-solving methods without preparation or experience, they tended to memorize procedures as they previously memorized facts in the traditional approach.

In the above studies, pupils themselves were active participants in the learning experiences associated with problem solving. With regard to the matter of individual laboratory experience versus lecture demonstration by teachers there has been considerable and continuing discussion in spite of the extensive research dealing with the problem over the years. For example, more than 20 years ago Cunningham (43) drew together all the research he could find dealing with the controversy and attempted to evaluate the designs used, organize the data gathered, and draw some conclusions from it. He studied 52 research reports, the majority dealing with secondary school science but some concerned with elementary, all exploring some aspects of the demonstration-laboratory experience discussion. He listed those conditions under which demonstration methods seemed most defensible and those under which individual experience seemed desirable. The use of both methods was recommended for variety and pupil interest; demonstration methods were recommended when time and equipment are limited and the process complicated or difficult; laboratory work was recommended when important objectives are the development of laboratory skills, the ability to solve laboratory problems, and the development of laboratory resourcefulness. This last recommendation seems especially pertinent to today's emphasis upon pupil involvement in the processes of science investigation.

Hamilton (83), pursuing a similar line of inquiry, recently investigated the relative merits of two methods of improving junior-high school pupils' skills of observation and inference-making. He divided a population of 72 seventh- and eighth-grade pupils into three groups—one group received instruction through discussion of single-concept loop films; another was taught through laboratory and discussion methods; the control group received instruction in regular science classes. A close approximation was planned between the observed science experiences in the loop films and the laboratory experiences in which pupils participated. Both the experimental groups made gains in skills of observation and inference-making, with no significant differences in results gained from the two methods. Students who were members of one or the other of the experimental groups were almost unanimous in their positive attitude toward the effectiveness of the method by which they were taught; yet all but three of the groups said they would have preferred the laboratory-discussion method had they been given their choice.

Interest in model formation as a strategy in the development of understanding in elementary science led Zeigler and Pella (220) to attempt to determine the relative effectiveness of the use of two kinds of theoretical mechanical models in teaching the concept of the particle nature of matter. Using Piaget's clinical approach with pupils from grades two through six, the researchers gave fifteen minutes of direct instruction to one group with a static mechanical model and with a dynamic mechanical model to another group; a third group acting as the control received no instruction. There were significant differences in achievement based on pupil responses to eight test demonstrations in favor of the treatment groups, but differences between groups using static and dynamic models were not significant. Children who had been identified by pretests as users of models performed at higher levels than those that were not so identified.

Recognizing that, in spite of evidences of its value, instruction emphasizing newer approaches to learning may not be easy for all teachers, Schippers (180) set out to evaluate instructional materials designed to develop the problem method in the sixth grade, to find out what difficulties teachers encountered, to identify the role of supervision in putting problem-solving approaches into action, and to study the questions children identified as a basis for their study. Twenty-four teachers used science units especially constructed for the study; some were given extensive materials and supervision; others worked with the materials without supervision. Schippers found that teachers could use his instructional materials without outside help, but that preschool workshops and illustrative lessons were distinctly helpful. The question-raising phase of the problem method proved to be the most difficult for teachers and getting adequate reference materials a stumbling block to extension of the problem method to other areas of content. In general, pupil achievement showed gains under the program, and teachers confirmed an increase in pupil interest and enthusiasm.

Although science educators will continue to welcome efforts to assess the value of new approaches by comparison with more established practices, there are certain pitfalls in such experimentation. Brownell (24:268-69) points out the wisdom of viewing all results from such comparison studies most cautiously, for these reasons:

1. In such studies it is possible to sample only a part of the possible content. With other content, results might be different.
2. It is unlikely that exactly the same content will be taught to all groups being compared, even within groups supposedly following the same program.
3. The influence of objectives upon the desirability of a particular program cannot be overlooked. For one objective, one approach may be best; for a different objective, another program may be more appropriate.
4. There is a strong likelihood that pacing of instruction may necessarily differ in the programs used, with the consequence that children pursuing unlike programs may be "caught" at different points in the attainment of given objectives.
5. The prescribed plan very possibly cannot be implemented by all teachers equally well.
6. The quality of teaching in comparison studies is extremely difficult to control.

Brownell believes that the extent to which these variables can be controlled will determine the significance of results derived from studies in which varying methods are compared for their effectiveness in reaching certain objectives.

It is becoming clear that direct experiences play a most significant role in children's science learning. Whether or not evidence will be found to prove that one method is superior to another, there seems, nevertheless, to be growing support for the idea that a wide variety of direct experiences improve children's concept development, their interest, their attitudes, and their scientific behavior.

Evaluating Performance in Elementary Science

With a shift from emphasis upon information for its own sake to concern for process, inquiry, and problem solving, new techniques of evaluation and particularly tests of concept development and scientific behavior have been eagerly sought after. There are some promising developments.

To illustrate that concern for evaluation is not entirely new, however, a brief review of some earlier studies suggests useful techniques. Observation remains one of the most effective ways of determining how children really function with their science knowledge and interests. West (212) used controlled observation by trained observers to record the action of children in terms of defined units of behavior which could be recognized easily during the observation period. Lockwood (130) used observation and survey questionnaires to study the nutrition habits of school children. Lichtenstein (126), in attempting to test the success of stressing an attitude, used records of children's actual behavior combined with an analysis of diaries which children were asked to keep of their activities.

Mathews (134) used the interview technique to evaluate third-grade children's understanding of some science terms and principles, asking children to talk freely about science situations in the form of games, pictures, and questions. Oakes (155), using the interview in finding out how young children explain natural phenomena, stimulated discussion through verbal questions and simple demonstrations. Hill (96), with the help of teachers, interviewed children to determine their perceptions of certain natural phenomena; her report suggests a technique applicable to other content as well. The interview technique was used also by Inbody (98) in collecting data about children's explanation of various demonstrated phenomena. And, of course, Piaget (163) makes clinical use of the technique in his studies.

Both observation and interview are being utilized in several of the new curriculum projects. For example, observation of pupil reaction is an important facet of evaluation in the Minnesota Mathematics and Science Teaching Project (129:191-92); and pupil interviews serve evaluative functions in the Science Curriculum Improvement Study (129: 219-22); Thier (196) describes the interview technique he used with two groups of 30 children, one group which had studied a unit on material things and another which had not. He used a script describing three situations and calling for pupil responses designed to evaluate understanding of the phenomena illustrated. His report includes the script and illustrates clearly how the technique was applied.

A problem that looms especially large in evaluating pupil achievement in new science programs, however, lies in the necessity for constructing tests that will measure something more than science information. In a recent article, Kurtz (120) makes a forceful plea for tests that test behaviors—behaviors which, of course, will draw upon pupils' store of science facts and their attitudes toward science. In another article Reiner (169) reiterates the challenge of recent developments in science in terms of developing new forms of evaluation; and in the same vein Walbesser (204) develops a scheme for the use of behavioral objectives as the basis for an instrument in which children carry out tasks which will reflect their degree of sophistication in applying the various processes of science. Construction of such an instrument is part of the projected work of the AAAS Commission on Science Education.

Newton (151) apparently shared the concern of those who think that many schools talk about desirable behaviors in science but do very little about them. Giving ear to critics who claim that problem solving is not a very vital focus in science education, Newton decided to proceed on the premise that the tests teachers give reflect their educational philosophy; thus, if problem solving was truly an objective of high priority, some efforts to evaluate pupils' competency would be discoverable in the tests they give. Newton analyzed 1906 questions from 57 different tests submitted by junior-high and senior-high teachers in 15 states, categorizing them either as factual questions or reasoning questions. He similarly analyzed the tests of textbook publishers. Less than one-fifth of the questions reviewed could possibly be identified as "thought" questions. It seemed obvious to the author that problem solving may have been "more myth than fashion" and that teachers certainly need to take time to prepare tests that do something more than ask for recall of memorized fact.

Butts and Jones (29) have developed an intriguing test designed to test the child as an inquirer, evaluating him by analyzing his methods of searching, processing data, discovering, verifying, and applying conceptual understandings to new situations. The test uses the tab-item format; that is to say, the child is presented with a situation and responds by removing tabs which reveal answers to the questions he selects in his search for information needed in solving a problem or in verifying his hypothesis as to the correct solution. The problem is presented to the child in the form of a physics problem-focus film. He then selects one of several possible solutions. If he is correct, he selects certain questions which, when their tabs are removed, provide data for verification; or if his initial choice is not correct, he proceeds to other questions to gather needed information to reach a solution. Ultimately he is given an opportunity to transfer discovered or verified concepts to new situations. The process is designed to reveal how the child goes about solving (or verifying), hence the order of the tab-pulling is significant and has necessitated a system of recording; the scoring of the test is based only upon the number of clues gathered and the logic of the order of the tab-pulling. Such a test seems especially appropriate to the new and increasingly enthusiastic concern for inquiry in the elementary science program.

Nelson and Mason (147) created and tested in use a measuring instrument designed to reveal whether or not pupils in grades four to six in five Michigan communities had developed skills and attitudes of problem solving as a result of direct teaching. The authors, attempting to overcome the usual criticisms of objective tests of critical thinking which fail to yield sharp discriminations, designed a test of comprehension in which pupils were required to apply learnings to new but related problem situations in such a way as to reveal their ability to discern the most appropriate of the solutions proposed. The authors' description in the cited report includes test items—situations followed by questions requiring critical thinking, arranged to lead the pupil through the situations in such a way that he must analyze his procedure in order to arrive at a conclusion.

Rowe (175), using a special technique for determining process, designed a study to examine a kind of learning in science which she calls context-learning. It is differentiated from concept learning in this fashion. When one can assign an object to a class of things designated in a certain way, he has the concept belonging to that class of things. However, the particular characteristics of any one of a number of things belonging to a class of objects changes in some degree according to the contexts in which it is used; and these contexts may actually assign the object to different classes of things. The author defines context as a "set of entities related in such a way that the meaning of any one of the entities is partly or wholly determined by defining the meaning of the set containing the entity. Context-learning is the process of forming such sets and assigning members to them" (175:18).

To examine her ideas, the author selected 60 boys in the fourth month of the first grade, distributed in three schools and among six teachers. In the treatments, subjects were required to solve task-oriented problems varied in context and concept by performing certain operations. In each context, the subject had to make decisions and put these into action. Analysis of his actions and his remarks, the order as well as the action, provided the data the author was seeking. By the end of a month the boys were showing marked differences in the way they processed data, and there was evidence that experience altered and modified patterns of responding in successive contexts.

Emphasis not only upon process but upon the development of science concepts rather than upon the memorization of facts has naturally led to a demand for ways of measuring concept development—techniques that have not been widely available up to the present. In an effort to assist in the solution of the problem of concept measurement, Butler (25) constructed and standardized an instrument designed to test concepts drawn from six areas—structure, metabolism, growth, reproduction, responsiveness, and adaptation—covering a grade range of one through six. The text consists of 35 plates, each plate composed of six pictorial items representing six percepts (defined by the author as knowledge of a single fact), each of these percepts to be attended to in answer to a yes or no question. For example, a plate may have pictures of six living things, to which the child must respond when asked, "Are these insects?" If the child responds correctly, the author assumes that the pupil knows what insects are and what they are not.

Such a test may be used as analytic, or diagnostic, or as a measure of achievement. When the test was put through a standardization procedure with 192 pupils of representative socioeconomic levels drawn as a sample from 50,000 pupils in Nashville, Tennessee, the range of concepts scores was from about 4.5 in the first grade to almost 19 in the sixth grade. On the basis of his results, the author believes that the test technique could be extended for use in higher grades. However, some question may be raised about the design of the study, insofar as pupils' knowledge of concepts is measured solely by a technique which emphasizes yes-no response with a 50-50 chance of correct response always present.

Similarly aware of the lack of instruments designed to test for concepts, Haney (84) developed a 48-item test of pupils' ability to classify animal characteristics. The technique was simply this—to present to the child four pictures of things alike in some way, followed by four pictures of other things, only one of which belongs to the first group of four. After giving the test to 796 pupils in grades three through six, Haney retained 40 items on the test, scaled in difficulty.

With a like concern for measuring comprehension of science concepts, Boener (20) constructed a picture test for use in kindergarten and grades one and two. The technique consists of a series of situations, each represented in the test by a set of line drawings. The set of drawings presents a science situation to which the child is asked to respond on the basis of his understanding of the concept being tested. Boener's use of the test has provided evidence that this mode of testing comprehension of concepts may be a fruitful one.

Of special interest in the identification of gifted elementary-school children with exceptional scientific talent is the Hunter Science Aptitude Test. Developed and validated at Hunter College, the test, described by Lesser, Davis, and Nahemow (124), measures ability to recall information, to assign meaning to observations, to apply science principles, and to use scientific method. The 91-item, two-form test seems to be a promising predictive instrument. Also interested in pupil achievement in science, Gehrman (72) studied the effect of test interpretation procedures on measured achievement and upon self-perception. Eighth-grade students in a large elementary school were placed in matched groups, one of which received in personal interview a positive interpretation of expected achievement test scores, another which received a neutral interpretation, and the control group which received no interpretation at all. Groups receiving test interpretation of expected achievement scored significantly higher on a selected standardized test in science than those who received no interpretation, but neither the positive nor the neutral interpretation showed significant advantage. And interpretation definitely affected pupil self-ratings and estimates of self-perception.

There is little doubt that the influence of new curriculum approaches and new emphases upon process and understanding in elementary science are having a wholesome and invigorating effect upon the search for improved evaluation techniques. Teachers have for so long been confined in their thinking and practice to the more readily available tests and techniques designed to measure only achievement of facts and information, that the present efforts in evaluation call for shouts of approbation, even though only the surface of the problem has as yet been attacked.

Improving Materials of Instruction for New Science Curricula

CURRICULUM innovations have consistently emphasized the importance of appropriate materials for study and experimentation, and teams working on new programs have produced booklets for pupils, guides for teachers, as well as films, filmstrips, and other aids. While many new curriculum projects have provided their own accurate and readable materials and tested them with pupils, current attention to fundamental principles and concepts, and concern for problem-solving methods leading to inquiry and discovery have also influenced the construction and commercial promotion of science textbooks and equipment and given impetus to careful study of those already in use.

Textbook and Programmed Materials

Attractive and interesting textbooks are being written for children currently by increasing numbers of scientists and educators. Karplus (109) particularly stresses the significance of the textbook as a means by which scientists may communicate directly with pupils and incidentally with teachers as well.

One of the problems in the use of the textbook continues to be the problem of readability. Mallinson, Sturm and Patton (133) were among the persons who early in the 1950's began to draw teachers' attention to the fact that science textbooks are difficult for those who are asked to read them. Mallinson (132) also drew similar conclusions regarding the reading difficulty of unit-type textbooks, recommending that such materials be shifted from one level to another as children's ability, rather than their grade placement, dictates.

More recently Ottley (156) undertook to find out whether the readability problem continues to exist. Using a revised Lorge technique emphasizing sentence length, vocabulary load, and idea intensity, he examined science series prepared for fourth-, fifth-, and sixth-grade levels by four publishers. He concluded that fourth-grade textbooks were too difficult for the lower half of the class, fifth-grade textbooks were less difficult but still too difficult for pupils in the lower half of the class, while the sixth-grade texts seemed best suited to the grade for which they were intended. He noted also that most texts showed no provision for reading growth from beginning to end. In view of the fact, however, that modern practice does not encourage or necessitate reading the textbook in any given order, this concern does not seem too significant at this time.

It *is* significant, however, to note that elementary science textbooks are being investigated with hypotheses other than readability in mind. Two concerns seem to be current. Weaver (208), for example, as a result of having taught a methods course in physical science for in-service and preservice elementary teachers, became increasingly aware of their misconceptions in science, especially in the physical sciences. He decided to attempt to get at the source of such misconceptions in physics or of presentations which would lead to such erroneous ideas. Of the 12 series explored none was free of misconceptions in physics. Two series were notably freer of errors than the others, but the results were disturbing enough to suggest caution on the part of teachers in the selection and use of textbook content in physics.

Because the textbook is frequently the curriculum guide to instruction in many schools, the grade placement of principles and the manner of their development in the textbook are also appropriate concerns for elementary teachers. Chinnis (32) analyzed six series of widely used texts to ascertain the grade-level placement of certain physical science principles, identified earlier by Robertson (172) and Leonelli (123), and to discover the manner and extent of the development of these principles. Chinnis' findings were rather startling: there was very little agreement among the series as to the principles to be developed, only ten of the 78 principles being developed in all series and half the principles developed in none or in only one or two series!

In the matter of grade-level placement, there seemed to be considerable agreement upon placing a large number of the principles at the intermediate level, but little agreement on exact grade placement. The analysis indicated that textbook authors developed principles more by examples in the environment, by pictorial means, and by experiments than by the writer's word. The results of this study raise some question about using any given series as the organizing instrument for an elementary science curriculum; on the other hand, unless current curriculum development projects shed some definitive light on the appropriate nature and content of the science curriculum, the textbook may continue to serve as the focal point for instruction in many schools.

In response to problems of readability and in an attempt to meet individual differences more effectively, Fryback (65) proposed to statistically evaluate new elementary science materials written at five reading levels, with student experimentation provided for at three levels of sophistication. Six treatment groups made possible the testing of the materials in several combinations of method and level. Results showed no significant differences in achievement in favor of groups in which each pupil read at his own level. There were significant differences, however, between groups that participated in experimentation and those that did not. The study seems to indicate that experimentation by pupils may contribute more to achievement than differentiated reading, although Fryback does suggest that further research should be undertaken to see whether or not pupil curiosity, creativity, and skill in inquiry are similarly unaffected by such differentiation.

The programmed text is a rather recent development in elementary science, and its extended use may have considerable influence upon the conventional textbook. Studies of the use of programmed materials have confirmed certain values—their contribution to pupil interest and motivation, their usefulness in meeting individual differences, and their values as in-service education for teachers. Several of these studies have evaluated the success of methods using programmed materials, have compared the method with conventional approaches, and have investigated use of programmed materials in various combinations of conditions.

McNeil and Keisler (137) attempted to determine whether or not instruction in the molecular properties of liquids, gases, and solids could be programmed and taught to a group of six first-grade pupils. The experimental group, when interviewed, was able to answer questions with content similar to that of the programmed materials, questions which a matched control group was unable to answer. However, these very young subjects were not able to generalize from their programmed experiences to examples not included in their original instruction.

Fourth-grade pupils have been subjects of two more recent investigations. Dutton (55) compared the achievement of fourth-grade pupils using programmed materials in the areas of sound, light, and heat, with the achievement of pupils taught by conventional methods. The researcher concluded that pupils at this level can proceed satisfactorily at varying rates through the materials, perform simple experiments with a minimum of teacher guidance, and learn science concepts more efficiently than do pupils being taught by conventional methods which do not utilize programmed materials.

Hedges and MacDougall (94) tested the use of programmed science materials, at the same level, coupled with an investigation of children's individual performance of simple science experiments. They found that pupils maintained high interest as they proceeded responsibly through the program and its correlated experiments.

Taylor (194) attempted to analyze the science achievement of fourth-grade pupils using programmed materials which included individual experimentation, in relation to the teacher's attitude toward the materials and to individual differences. The results seemed to indicate that while teacher attitudes accounted for only 18 percent of the variance in final achievement of the pupils, they implied that a positive and encouraging approach on the part of the teacher has its role to play in successful use of such materials. In the matter of individual differences the results seemed to show that initial knowledge of science and other personality and performance characteristics were significantly related to achievement with the materials and that the materials themselves as written did not fit the abilities of all levels of intelligence in the group.

Radio and Television

Not only are printed materials in science growing in number and quality, but complementary resources are also becoming more and more versatile and effective.

Radio and television have long been accepted community resources available for instruction; and educational television programs are now a part of the school day in many schools. In the early 1950's instruction in science by radio was favorably reported by Dillon (52), who directed a program of science experiments for middle-grade children, who in turn participated in the experiments during the program. Wentz (211) a little later described science instruction by radio in St. Louis, Missouri, where radio and pupil participation again combined to teach important science concepts.

While radio has been overtaken in popularity by educational television in many school systems, there is still interest in radio where educational television is not available. Very recently Constantine (36) used radio as a motivating device in science instruction for 30 fifth- and sixth-grade pupils, similar in physical make-up and achievement; one group used traditional teaching methods without radio and the other used radio extensively. Findings seem to show that the use of radio was an effective motivating force in helping the experimental group surpass the control group both in work skills and in science information.

Interest in educational television has grown by leaps and bounds in the past ten years. In the middle 'fifties descriptions of successful teaching of science by television were being published (30, 107) but little research was as yet available. Currently data are being accumulated to test the effectiveness of television instruction from a variety of points of view.

One elaborately designed study sponsored by USOE has been reported by several researchers. Garry (71) initially reported research on science teaching by television in the elementary program. The purpose of the study was to determine the effects of teacher training, method of presentation, teaching method, and pupil activity upon the achievement, interests, attitudes, and scientific reasoning ability of fifth-grade pupils studying natural science by television. About 2,600 pupils in 90 fifth-grade classes in the Boston area used a series of 30 half-hour natural science programs produced by the Massachusetts Audubon Society and designed to develop understanding of the relationship of all living things to their environment. Eighteen classes in the control group received only television instruction; seventy-two received instruction by television under a variety of conditions.

The variables, the effects of which were sought, were these: (a) Preparation of teachers for use of television compared with no such training. (b) The use of television programs to initiate or terminate classroom instruction. (c) The use of a comprehensive study guide by teachers or use of a brief outline of the television program. (d) Participation of pupils through individual projects or through common class assignments. (e) Sex and intelligence as indicated by the IQ. In addition, four-way analysis of variance permitted the investigation of eleven interaction effects of the above variables. Experimental groups had large statistically significant differences in science vocabulary and information over the control group. No significant differences were found in the two groups in scientific reasoning ability or interest in science, nor did pupil attitudes toward science and scientists change readily in either group.

Although the main experimental effects taken singly produced no significant differences between experimental classes, there were such differences on certain interactions. For example, where television programs were used as a terminal activity, greater learning occurred when the class assignments were made by the teacher and were common to all; whereas, when television was used to initiate a program, individual project assignments were most productive of learning. The preparation of the teacher and the type of study guide used seemed to make little difference, although differences in skill among teachers yielded some considerable differences. One startling result was that pupils of high initial interest

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and those of high intelligence tended to lose interest as the school year progressed!

Dietmeier (51) reports on a specific aspect of the above study, his concern being the effects upon scientific reasoning of various means of handling television in the classroom. As reported above, the experimental variables did not produce significant differences in scientific reasoning, although there were indications that there may be a relationship between scientific reasoning and motivation. Moreover, there were no differences between fifth-grade boys and girls in the ability to do scientific reasoning; nor were gains in scientific information accompanied by parallel gains in reasoning ability.

Kraft (117) was also responsible for a particular segment of the USOE study, her problem being that of studying the effectiveness of various methods in the use of instructional television in terms of pupil gains in information and vocabulary achievement. The tests used to secure data for this phase of the study were a 75-item, multiple-choice science information test correlated with the television program and a 150-item matching science vocabulary test; both tests were administered three times during the school year, permitting comparison of mid-year with end-of-the-year gains. Gains in achievement were greater under all combinations of experimental variations than when the television course alone was used as in the control group. Each IQ group in the experimental classes showed greater gains than its equivalent control group and greater rate of gain. As reported above, certain combinations of viewing and assignment were more effective than others. However, gains in vocabulary were not dependent on any specific experimental treatment or combination. Kraft logically concluded that passive use of television will not yield the learning that occurs when television lessons are supported by varied classroom activity. In other words, television does not make the teacher dispensable.

Amirian (3) reported later on the final phase of the project discussed above, his concern being to evaluate the effects of the variables previously described upon pupil retention of information and upon interests and attitudes. He concluded that methods used in the teaching situations in this study bore no significant relationship to the process of retention; in other words, the methods may have improved learning but, when learning had taken place, retention and forgetting were another matter. He suggests further research to investigate the effect of television instruction upon retention of science material and its effect upon changes in interest and attitudes.

In recent years, midwest schools in a five-state area have been receiving educational television from an airborne transmitter in a project originally financed by the Ford Foundation. Thompson (197) reports a study designed to determine whether or not intermediate grade pupils learn science as well when taught with the help of television as when taught without it and to ascertain the effects of television instruction when ability, grade, and sex are considered as variables. Twelve fifth-grade and nine sixth-grade classes were the subjects of this study in which 13 experimental groups received instruction twice weekly from MPATI (Midwest Program Airborne Television Instruction), and control groups were taught by conventional methods with a common text, a curriculum outline prepared by the staff, and MPATI guides. At the fifth-grade level, scores on standardized achievement tests were significantly higher for the experimental group, although, at the sixth-grade level, only scores on one of the two tests used were superior in the experimental groups. Boys were somewhat superior to girls and high ability pupils to lower ability pupils.

Although reports of studies involving television instruction describe generally positive results, a word of caution is in order. It is well to remember that the medium is only as good as the television teacher and only as effective as the use made of it by the "live" teachers of children in the receiving classrooms. It might be better, then, to concentrate on comparing varying uses of the television medium itself to discover ways in which it can make the most effective contribution to science instruction.

The use of closed-circuit television in the classroom as an answer to the problem of overcrowding was the interest of Montag, Dubridge, and Samuels (139). Demonstrations and experiments conducted at the teacher's desk were observed by large groups of pupils by means of monitors which brought each detail as close to the pupils as though they were at the instructor's desk. The teacher observed pupil reaction, backtracked if there was misunderstanding or question, and answered questions as these arose in the group. At the end of the year, when students were asked to compare the technique with conventional classroom instruction, one hundred thirty preferred the television approach; thirty-three did not. The researchers concluded that there were positive possibilities from such use of television, and they plan more advanced equipment for further study and use.

Filmed Materials

Films continue to be useful in teaching elementary science concepts, although little recent research has come to light. Early in the 1940's

Cobbs (35) found ample evidence that the use of films contributed to the learning of natural science by very young children, findings later confirmed in a study by Nunnally (154).

Recently Allison (2) investigated the effect of the use of ten motivational films on the attitudes of fourth-, fifth-, and sixth-grade pupils toward science, scientists, and scientific careers, discovering that each of the various treatments he used seemed to produce favorable changes in these attitudes. Filmed science demonstrations have served prominently as stimulus material in experimentation by Suchman (192), Weigand (210), Butts and Jones (29); and films have been an important segment of the resource materials constructed in certain of the new curriculum developments. For example, the Elementary Science Study (129:140-60) relies heavily upon 16mm sound and 8mm film loops, the latter a rather new development in visuals.

Equipment

Equipment for teaching science has high priority in a number of studies spanning the past 15 years. That teachers are aware of the need for improved facilities for science instruction was emphasized in a study by Witherspoon (214), in the early 1940's and later confirmed by Piltz (165) and Sachs (177). The availability of materials and equipment from local sources was the subject of discussion and study by several writers—Raskin (168), Mullen (143), and Grant (77) are examples.

Currently the identification, construction, and use of instructional equipment are receiving attention in most of the curriculum studies around the country, with kits and portable laboratories available to participants. Lipson (127) reports efforts in the Learning Research and Development Center of the University of Pittsburgh to plan for the elementary school 30 lessons for individualized laboratory instruction in the study of light and its properties. The subjects use kits of materials and tapes to provide experiences with real objects, followed by special tests of performance to measure their achievement. Results thus far have led the researcher to conclude that the laboratory is an effective tool in concept development in young children. Novak (153) reports a study in which audio-taped programmed science lessons combined with loop films and real materials for observation are used in a study carrel by individual children of primary level in studies of plant growth. The preliminary data have shown that pupils are successful in their use of the carrel and its equipment and that study of their concept development is greatly facilitated by the elimination of teacher variables.

With the availability of many new materials both commercial and sponsored, interest in their relative merits has been lively. Berkheimer (15) reports a study on the role of the science supervisor in the selection and utilization of these materials. Responses from almost a thousand supervisors and teachers indicated that supervisors who were involved in programs utilizing commercial materials appeared to encourage teacher demonstration, emphasis upon facts and principles, units of content, and qualitative observations; supervisors involved in programs making use of materials such as those sponsored by the National Science Foundation appeared to be more concerned with encouraging teachers to try new ideas in program planning and classroom methodology and with encouraging pupils to use laboratory equipment, to employ methods of scientific investigation, and to make quantitative observations. Apparently, the differences existing between the two groups were related to the approach to teaching underlying the development of the materials themselves.

Newport (150), however, raises the question of availability to pupils of some of this equipment in schools where adaptations of new curricular plans are being made; he considers the requirements in some to be unrealistically extensive. On the other hand, recent availability of moneys from outside sources has been of tremendous assistance to schools that could not otherwise have met these demands for new materials and equipment.

Criteria for selection were the concern of Ricker (170) in his study to identify guidelines to assist in the choice of science equipment. Results showed lack of equipment to be a problem for about one-third of the more than 400 teachers who participated in the study. Although half of the teachers had learned to use equipment through reading, they were not in agreement as to effective methods of helping teachers gain such knowledge. It was obvious from their responses that teachers were not familiar with all items, that they did not know whether such equipment was available or suitable, and that they overlooked or did not know the reasons for using certain items of equipment.

Available research indicates interest in providing adequate learning materials for elementary science. While major attention has been given recently to the production of scientifically accurate reading materials, there has been no lack of concern for the location and use of appropriate visuals and equipment.

Improving Teacher Education in Science

IN ALL studies concerned with the improvement of elementary science curricula attention is being directed toward the competency of the teacher, his science content background, his problems in teaching, and his attitudes toward science. In experimental studies comparing methods of instruction in elementary school science, the factor of teaching excellence is always a significant one. What has research discovered about teacher education in science?

Teacher Preparation in Science

Adequate content background has long been an unrealized goal for the elementary teacher. The very nature of his work, which has required him to be effective in multiple areas of the elementary curriculum, has militated against his becoming expert in any one. To insist that the elementary teacher be well-prepared in all phases of the physical and biological sciences is unrealistic in view of the fact that such extensive preparation would most certainly decrease the teacher's time for other important disciplines. Nevertheless, all over the country, teachers continue to fall far short of the reasonable 20 hours of science in a four-year college program, recommended in 1947 by an authoritative yearbook (145).

In Gemmill's (73) study reported in 1937 of practices in 16 representative institutions in 10 states, one-half the students surveyed had been graduated with only one course in science and some had entered elementary teaching with no science course of any kind. Presently one might expect to find some improvement in the college preparation of teachers as a result of the increased national interest in scientific exploration and development, but such improvement has come but slowly.

For example, in 1961 Washton (206) reported that among a group of 100 young elementary teachers who from 1953 through 1958 had taken a graduate course in the teaching of elementary school science at Queens College only five had had more than one year of college science as undergraduates. In a study of a more limited sample of teachers from

Cumberland County, New Jersey, Wytiaz (216) discovered that in a group of 70 fifth-grade teachers over one-half had taken a biology course, two-fifths had had a chemistry course, and nearly two-fifths had taken both botany and physics. Slightly more than one-fourth had had no course in methods of teaching science to children. When one considers that elementary school science ranges over five science areas, it is obvious that inadequacies in preparation still exist.

Several studies in the 'sixties indicate that teachers themselves recognize their lack of science background. Crawford (39), in working with the county elementary schools of Maryland, discovered that both teachers and administrators identified improved teacher preparation as a major need in curriculum improvement. More than half the teachers in the study by Wytiaz (216) felt that they had insufficient knowledge for teaching science in the elementary school. Victor (201), after exploring elementary school teachers' reluctance to teach science, concluded that inadequate experience with science content is definitely a factor in teachers' insecurity.

Hardin (86) undertook to evaluate the adequacy of the program in science offered at the University of Miami for prospective elementary teachers. Using a test constructed to reveal competency in elementary science in general and in certain sub-areas (minimal essentials), he tested 199 juniors and seniors who had taken courses in both the biological and physical sciences and had completed a methods course. The results of the test led Hardin to conclude that the prospective elementary teachers were inadequately prepared and the inadequacy was about the same for all the sub-areas tested.

On the other hand, when Groff (81) asked 645 student teachers from six different California colleges to rank in order the subjects they thought they were best prepared to teach, they ranked science fifth in a list of eleven. Apparently they considered science neither the most nor the least difficult, and felt somewhat better prepared to teach science than other studies included here might lead one to believe. Esget (58) was interested in finding out whether or not prospective elementary teachers showed more growth in knowledge and understanding of elementary science after taking a course in which elementary science methods and content were combined than did those who had taken a course only in methods. Using an instrument which he devised, the researcher found that his results favored the course which combined methods and content.

Because, as Craig (38) pointed out in a very early study, teachers need knowledge in five science areas in order to answer the questions of children, it is useful to know whether or not teacher inadequacies apply to all phases of science or only to certain areas. When Beringer (14) administered a scientific fact test to several hundred elementary teachers in southern California, there were more correct responses to biological science statements than to physical science statements. The teachers in Wytiaz's (216) study felt best prepared to teach about plants and least well-prepared in the physical sciences. The 106 teachers in an Illinois study questioned by Victor (201) considered chemistry the most difficult to teach followed by physics, astronomy, geology, and biology. Wishart (213) discovered that teachers with the most credit in college science tended to teach more physical science as part of their instructional program, while teachers with the most preparation in professional education tended to teach more biological sciences to their pupils.

Tests of teacher understanding of scientific fact also support the conclusion that there is close relationship between understanding of science concepts and number of college courses in science. The Beringer (14) study showed better understanding on the part of teachers with the most recent college training, the implication being that they probably had more science content in their college programs. In the Wishart (213) study the best scores on a high-school level achievement test in science were earned by teachers with the most college credit in science. Moreover, 63 of the 100 teachers studied by Washton (206) entered their graduate science methods course without a knowledge of science equivalent to that possessed by ninth-grade pupils.

It might be assumed that if undergraduates in teacher education could be made aware of the need for more college science courses, they would try to improve their science background by electing to build strength in areas of weakness. Some such assumption may have led Twyman and Marsden (198) to try to determine whether the student teaching experience during the junior year of teacher education could be used to help students discover their needs for strengthening certain academic areas, especially science and mathematics. However, there was no appreciable difference in number of science courses taken between the junior-year student teachers (who would have had opportunity to elect additional courses after student teaching) and the senior-year student teachers (who had no opportunity to take additional course work).

In the opinion of teachers, however, the mere acquisition of college credits in science will not guarantee improvement in science instruction in the elementary school. Witherspoon (214) reported that teachers are most interested in courses that will help them present science as it should be presented in the elementary school, and Bolen's (21) recommendations included a plea by teachers that college courses be less theoretical and more practical, less formal and more in the workshop manner. These studies were echoed more recently by Wytiaz (216), Beringer (14), and Washton (206), whose subjects emphasized the importance of providing a science program geared to the needs of elementary teachers and of relating college science work to solving problems of everyday living.

Butts (27), however, after testing twenty-one college seniors who averaged 17.4 hours in college science and evidenced above average interest in science, raised other concerns. He found that on the test, which was designed to reveal students' problem-solving behavior, the subjects did not characteristically show patterned thought. These results suggested to Butts that since there seemed to be not one but several ways to solve problems, course work for those preparing to teach science should perhaps be directed to the development of science attitudes and a reasonable program of basic principles and generalizations rather than to specific steps in problem-solving behavior and the accumulation of knowledge.

In the past few years many teacher education institutions have been studying and revamping their science programs for teachers, although few have been the result of extensive research into present practice and teacher needs. A study by Service (184) is, however, an example of a more systematic approach to science curriculum revision for the preparation of elementary teachers. He analyzed current purposes and content in science education in California colleges, investigated requirements for elementary education in selected institutions, and made recommendations regarding the nature and substance of academic science subject matter preparation for the prospective elementary teacher. He found that the content of elementary science, covering the whole scope of science with emphasis upon open-ended investigations, was an unrealistic demand upon teachers graduated from colleges where science requirements varied from eight to twelve units. His proposed program of science preparation included "broad background in biological, physical and earth-space sciences" as well as studies in depth in some aspects of each science area.

Not only is effort being made to provide better preparation for teachers in the basic courses in science, but attention is also being given experimentally to the improvement of courses in methods of teaching science in the elementary school. Lacey (121) reports a study of a Hunter College project designed to determine whether or not the methods of teaching science courses might be revised to enable elementary teachers to teach science with greater competence and confidence. The experimental group was led "to investigate the processes and structures of science in a problem-solving and inductive manner" with emphasis upon intellectual skills and attitudes characteristic of scientific inquiry; the control group was subjected to the usual "teacher-dominated" traditional approaches. Although there were no significant differences in the gain made by the two groups, the experimental effort resulted in overall improvement of materials, equipment, and facilities, increased cooperation between education and science departments, and the construction of useful evaluative instruments. The study raises the question of how best to determine whether or not problem-solving techniques and student-centered practices are best at the teacher education level; obviously in this study the either/or concept of method did not produce definitive results.

Kellogg (113), also interested in improving methods courses for prospective teachers, sought to determine which of two methodologies could enhance elementary education majors' ability to analyze and interpret graphs. Students in Group A were taught by a laboratory-discovery method in which participants experimented, observed, collected and plotted data on graphs, and drew conclusions from these representations. Those in Group B were taught through discussion and demonstration directed by the instructor. Kellogg found no significant difference in the gains of the two groups, although Group A appeared to value its experiences more than did Group B. Furthermore, although results were not subject to measurement in the study, skills in using equipment, measuring, recording data, and making graphs were unique to Group A.

Wright (215) describes efforts at the University of Arkansas to study the relationship between teachers' adherence to principles of child development and the activities, understandings, and learnings stressed in elementary classrooms and in professionalized science courses for elementary teachers at the college level. Results of achievement tests in the selected classrooms showed that the pupils made an average gain of nine years in grade five and four years in grade six and were showing increased interest in science as well as gaining insight into its processes. Professionalized courses were planned to help teachers learn the characteristics of elementary school pupils, to develop skills needed in teaching science, and to gain essential scientific information; courses were taught by procedures similar to those used by the selected elementary teachers. The study led to the conclusion that there is definite relationship between emphasis upon child development and the successful teaching of elementary science, coupled with the suggestion that further research of a longitudinal nature be conducted to determine long-range values of such an approach.

Also focusing upon teacher education in science, Kriebs (119) used video tapes with two groups of pre-teachers. The experimental group viewed taped classroom science lessons; the control group viewed taped lecture-demonstration lessons. Students in both groups planned and taught a pre-video and post-video lesson to a class; their lessons were taped. A study of the tapes and of other data indicated that the control group gained more in science knowledge; the experimental group showed more improvement in specific techniques of teaching; the control group regressed in techniques. Apparently viewing classroom science lessons enhanced the pre-teacher's security and know-how but did not improve his store of science knowledge.

In-service Education of Teachers

Although increasing emphasis upon better preparation of elementary teachers is certain to improve science education as times goes on, for the many classroom teachers who probably will not return to formal college course work, in-service education must function to remove deficiencies and to bolster confidence. In Frazier's (64) excellent discussion relative to the implementation of national curriculum studies, he emphasizes the essential role of in-service education in helping teachers to undertake new tasks and to perform in new ways, and the critical services to be provided by adequate supervisory and consultant personnel.

Of growing importance in the in-service education of teachers in science are the science institutes being sponsored by national groups and by the federal government. Since admission to these institutes is usually by selection after application, data on this population are readily available for study. Gallentine and Buell (70) examined the characteristics of a group of applicants who appeared to be generally representative of Ohio elementary school teachers but rather unusual in one respect. Not only had the applicants averaged 14.9 credit hours in college science, though the range was from 0 to 35, but also each reported a high interest in self-improvement accompanied by a regular reading and study program in science. These teachers were in contrast to non-applicants who in related studies were found to be less motivated and more self-satisfied.

Workshops that make available a wealth of facilities, an atmosphere conducive to free exchange of ideas, opportunities to plan the work cooperatively, and assistance in developing materials for the classroom were enthusiastically favored by teachers questioned by Bingham (17). Lakin (122), interviewing teachers using aviation materials provided for California elementary schools, found that workshops that involve teachers in the use of materials they must in turn use in the classroom were highly valued by their participants. Karplus (109), in his review of the first year of a curriculum study project at the University of California, recommended a laboratory teaching program in which teachers have multiple opportunities to teach a science lesson, repetition that would substantially contribute to teachers' security, helping them to become familiar both with content and with pupil responses. Lester and Baker (125) describe a USOE in-service project in Georgia in which a combination of telecasts for teachers and consultation with university scientists prepared teachers for use of educational television in the classroom; teachers' reaction to these procedures was definitely positive and cooperative.

Brittain and Sparks (23) noted that after a series of weekly hour-long telecasts sponsored by the National Science Foundation, teachers listed fewer teaching difficulties than before; however, certain difficulties were thought to be more serious by intermediate-grade teachers, and the more substantive the learning the more difficulties in teaching were identified. On the other hand, Beringer (14) concluded that further research is needed to determine exactly what teachers need to know and what type of in-service assistance is most effective in helping them keep abreast of current thinking in science.

More and more communities are including in their in-service efforts the science consultant, a person who is not a supervisor but a helping teacher with special competencies in teaching science. The consultant may or may not participate in classroom instruction, but his task is to assist the classroom teacher to do the best possible job of teaching science. The characteristics and techniques of an effective consultant are charmingly detailed in a publication by Greenlee (80).

The contributions of the consultant and of the special teacher have been touched upon also in several research studies. Crawford (39) recommended the use of "key teachers," or helping teachers, to work with the supervisory staff in science and to provide that personal assistance that can be so effective if available at just the right moment. Gibb and Matala (74) found some evidence that children in grades 5 and 6 learned science more effectively with special teachers than in self-contained classrooms. The teachers in the study by Wytiaz (216) were about evenly divided in their opinions as to whether or not science should be taught by a special teacher.

Ginther (75) and Payne (159) tested two uses of consultants—one in which the consultant worked primarily with teachers and another in which the consultant taught the pupils once a week with the classroom teacher following through with what the consultant had started. Results favored the situation in which the consultant worked primarily with teachers. Jones, Moore, and Waechter (104) studied two methods of introducing science using 1650 pupils in the intermediate grades and 55 teachers. The experimental group was provided with consultant help in developing materials, in identifying concepts to be taught, and in devising methods for teaching; the control group received teaching outlines but no other help. Children's achievement and attitudes definitely supported the in-service effort. These studies suggest that as yet there is no conclusive evidence to support either the self-contained classroom idea or the special teacher practice; perhaps it can be said only that assistance to teachers must meet their particular individual needs—consultant service, "helping teachers," or special teachers, as the case may be.

Abramovic and Stotler (1) describe a rather unique plan for effecting curriculum change through direct assistance to teachers in elementary science in Portland, Oregon. A customized guide in the form of keysort cards and a thoroughly tested science test are the major items in this special concern for helping teachers provide effective and well-chosen experiences for pupils. The STAC cards (Science Teachers Adaptable Curriculum) are programmed through teacher committees at three elementary levels; each card contains teacher instructions, ideas for investigations, experiments, reference readings, and visual aids, all carefully selected and continually revised to conform to the current trends in content selection and methods.

To use the card system, a teacher selects, by inserting a sorting needle, cards for the particular level desired; he may further sort out particular topics or special aspects of the curriculum in the same manner. It is important to know that the STAC cards are so planned that pupils will engage in smiliar basic experiences, regardless of the choices the teachers may make. The Portland Science Test has two sets of items—process items planned to test problem recognition, hypothesis choosing, and experiment choosing and product items designed to test recall of scientific information. The authors of the report believe that these two techniques supplemented by in-service education in their use are helping Portland teachers reorganize their science curriculum in a scientific way, making it respond flexibly to evaluation and change.

Basic, of course, to teacher interest in in-service aid of any type is the teacher's personal involvement in the science program and his concern for its effective implementation. Here should be mentioned research by Uffelman (199) in which he tested the relationship between the degree of teacher involvement in curriculum improvement and its related in-service classes; he concluded that the degree of personal involvement was positively related to teacher approval of the program. However, Uffelman warned that teacher selection could have contributed to his rewarding results. The importance of teacher education in the improvement of elementary science can hardly be overemphasized. Both preservice and in-service efforts will no doubt continue under the impetus of new experimentation and new program proposals. There is wide interest on the part of teachers and ample evidence that cooperative planning and development efforts do indeed give teachers needed security and new success in what has been traditionally considered a difficult subject area.

Conclusion

THIS summary of research is surely evidence of the lively interest in elementary science education today. The amount and kind of research are quite in contrast to that reported in 1957 in *Elementary Science: Research, Theory, and Practice* (54), when very few aspects of elementary science had been explored systematically in any depth; when expert opinion and current practice supplied many of the ideas gathered together for the publication; and when research needs for the future were many.

The situation is vastly different today. Curriculum research is extensive; objectives are being redefined and clarified; children's learning is being examined from varied points of view; new materials are being designed and tested; methods of search are being emphasized and compared to more conventional approaches; tests of comprehension and problem solving are being constructed and evaluated; varied types of pupil organization and varied uses of consultants are being examined in experimental situations; and preservice education continues to receive attention.

Furthermore, there is every indication that research in these and related fields will continue and even accelerate. Of primary concern on all fronts should be, according to Washton (207), research in the teaching of science for creativity. He identifies several needs that merit priority—the need to determine when certain types of pupil questions can lead to creativity; to identify science students who are creative, not merely intelligent by some standard measure; to study pupils' ability to raise significant problems for study; to find out how pupils can be led to experiment, to accept or reject hypotheses they have formulated; to study the relationship of teacher creativity and flexibility to creativity in children. Surely these mandates serve to emphasize that there is still much yet to be learned and that very little in elementary school science is escaping the penetrating attention of science educators.

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